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Ansökningsnr
Ankom

Ansökan om projektmedel

Ansökan avser nytt projekt ☐ Fortsättning på tidigare projekt, nr 502-061	
Ansluter ansökan till Brandforsks program ☒ Ja, problemområde 3, 6 ☐	
Sökande Namn (företag, el dyl), adress, tel, fax, e-post	Avdelningen för Brandteknik och Riskhantering Lunds Tekniska Högskola Box 118 221 00 Lund 046-288 48 39 patrick.van_hees@brand.lth.se
Projektledare Namn, adress, tel, fax, e-post (Bifoga CV)	Patrick van Hees Avdelningen för Brandteknik och Riskhantering Lunds Tekniska Högskola Box 118 221 00 Lund 046-288 48 39 patrick.van_hees@brand.lth.se
Projekttitel	PRISME 2 – Validering och användning av brandprovningar vid underventilerade förhållande
Projektbeskrivning Sammanfattande beskrivning (syfte, metod, förväntat resultat, målgrupp) Fullständig beskrivning lämnas i bilaga.	Mellan 2006 och 2011 utfördes ett internationellt OECD/NEA projekt med namn PRISME. Den svenska delen av PRISME 1 är nu slutrapporterad. I projektet studerades underventilerade bränder via flera fullskaleförsök som genomfördes hos IRSN i Frankrike. PRISME projektets provningar finansierades av NBSG (Nationella Brandsäkerhetsgruppen där SSM, Forsmark, Ringhals, Oskarshamn och SKB ingår). Bredvid projektet som finansierades av OECD/NEA fanns även ett projekt som finansierades av nationella resurser och som undersökte möjligheter av olika programvaror som t ex zonmodeller och CFD modeller. Möjligheter och begränsningar undersöktes via valideringsövningar. Finansiering av denna del gjordes gemensamt av NBSG och Brandforsk. Brandforsk projektets rapportering har nu genomförts. Utöver referens till rapporter finns två publikationer bifogad i denna ansökan. Under det första PRISME projektet visades sig att flera kunskapsluckor fanns inom bland annat underventilerade bränder, som därför kräver ytterliga forskningsinsatser. Ytterligare exempel på scenarier som medförde svårigheter var bland annat läckage via öppningar mellan rum i två våningar, sprinklade rumsförsök vid underventilerade förhållande samt realistiska kabelbränder. Det skapades ett PRISME 2 projekt som startade redan den 1 juli 2011. Bredvid provningar som finansieras av OECD/NEA och de olika deltagande länder (för Sverige finansieras försök av NBSG) startades även ett projekt som finansieras enbart med nationella resurser och som behandlar validering av datorprogramvaror. Viktiga delar av detta projekt är bland annat blinda och öppna simuleringar av de provningarna som utförs inom PRISME2. Information av de valideringarna som skall utföras inom projektet är viktiga för att bestämma osäkerheter i simulering av bränder vid brandteknisk dimensionering. En viktig del i arbetet som kommer att genomföras i den föreslagna svenska delen av projektet är bland annat validering av den nya ventilationsmodulen i FDS. En första validering i PRISME 1 har visat stora möjligheter av denna modul inte enbart för kärnkraftverk men även för

	byggnadstillämpningar. Validering av FDS och även utvärdering av andra mjukvaror är ytterligare ett syfte med det svenska projektet. Även utveckling och validering av en modul för simulering av pölbränder i FDS är ett syfte. Sista syftet är användning av provningar i PRISME 2 för svenska förhållande. Ett resultat av projektet är en översikt av möjligheter och begränsningar av mjukvaror för prediktering av underventilerade bränder men även för ventilerade utrymme. Ett annat resultat kommer att ge oss osäkerheter av simuleringsverktyg via blinda och öppna simuleringar, en viktig del för brandteknisk dimensionering. Projektet resulterar även i en pyrolysmodell för pölbränder som tillåter flexibla simuleringar av effekt av en pölbrand som tar hänsyn till geometri och ventilationsförhållande. Pyrolysmodellen är en del av ett NKS-projekt (Nordiska Kärnsäkerhetsforskning). Målgruppen för projektet är industri, konsulter, forskningsinstitut och myndigheter. En fullständig projektbeskrivning på engelska samt innehållet av PRISME 2 projektet och sammanfattande resultat från den svenska PRISME 1 projektet finns i bilaga (artikel från SMIRT 2011 konferens).
Projekttid	Startdatum 20120601 Slutdatum (färdig slutredovisning) 20170101
Projektorganisation Förteckning över personer som deltar i projektet samt deras funktion.	Patrick van Hees, Projektledare Jonathan Wahlqvist, doktorand Simo Hostikka, PhD, VTT (ansvarig för en del av NKS projektet) Bjarne Husted, Ass. Prof., Haugesund University College (ansvarig för en del av NKS projektet) Tommy Magnusson, Ringhals AB, (ansvarig för PRISME 2 OECD delen samt en del av NKS projektet) Fredrik Jörud, OK GAB (ansvarig för en del av NKS projektet)

Ansökt belopp (från Brandforsk)	**1250 kSEK**
Totalkostnad för projektet	**Svenska delen: 6350 kSEK (Kostnaden för hela PRISME II OECD projekt 70 MSEK)**
Annan finansiering utöver Brandforsk	Medel har även sökts hos: (namn, belopp, ange om det beviljats) NBSG har finansierat de provningar inom OECD NEA projekt (beviljats) 4000 kSEK NKS (Nordiska kärnsäkerhetsforskning) har finansierat utveckling av poolmodellen i projektet: 1100 kSEK (990 kDKK). År 1 och 2 är beviljat. (NKS beviljar årsvis, år 3 återstår)
Rapportering	☒ Projektrapport, 2 CD (*obligatoriskt*) och pdf fil med rapport ☒ Underlag för Infoblad (*obligatoriskt*) ☒ Artiklar ☒ Seminarium ☐ Annat
Övriga upplysningar	-
Datum och underskrift	2012-12

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2008-12-01

Project description PRISME 2 – Swedish Project – Validation and use of test results for under-ventilated fire scenarios

Background

PRISME 1

The first PRISME project [1] was an OECD/NEA project with participation of the following countries:

- Belgium
- Canada
- Finland
- France
- Germany
- Japan
- Netherlands
- Republic of Korea
- Spain
- Sweden.
- United Kingdom
- United States

The budget of the project was 7 M€ and the project time of the project was from January 2006 to June 2011. The major PRISME project financed fire tests at IRSN (France). A project and management group was established by means of the contract and had meetings at least twice a year. During the meetings the technical content and scope of the project was discussed.

PRISME is the French acronym for "**Pr**opagation de l'**I**ncendie lors de **S**cénarios **M**ulti-locaux **E**lémentaires" which is translated to "Fire Propagation in Elementary Multi-room Scenarios". The project mainly aims on studying smoke and hot gases propagation in full scale, well confined and mechanically ventilated fire compartments.

The PRISME project consisted of a series of fire and smoke propagation tests in a dedicated facility at the French *Institut de radioprotection et de sûreté nucléaire* (IRSN) centre at Cadarache, France. The facility is used to investigate room-to-room heat and smoke propagation, the effect of network ventilation and the resulting thermal stresses to sensitive safety equipment of such room configurations.

The project (citation from reference [1]) aimed to provide such critical information as the time that elapses before target equipment malfunctions and to qualify computer codes modelling heat and smoke propagation phenomena. The objective was to answer questions concerning smoke and heat propagation inside an installation, by means of experiments tailored for code validation purposes.

Several propagation modes were being studied: through a door; along a ventilation duct that crosses the room containing the fire and that ventilates an adjacent room; along a ventilation duct when flow is reversed within and through leakages between several rooms.

Apart from the project, which incorporated the fire test, a separate project dealing with validation was conducted, the so-called benchmark project. This project was not covered by a contract but was conducted based on national resources. It was in this project that the major activities of the previous Swedish PRISME project, sponsored by NBSG and Brandforsk, could be situated. NBSG is the national fire safety group for nuclear power plants consisting of the Swedish Nuclear Power plants in Sweden (Ringhals, Oskarshamn and Forsmark), The Swedish Regulator SSM and the Swedish Nuclear Fuel and waste Management (SKB). The PRISME 1 project, both at national and international level, is now in its reporting phase but the new project PRISME 2 has already started from July 1st 2011.

A number of publications are available for results of the overall PRISME project [2] [3].

The major result from the benchmark exercise in PRISME1 can be found in annex 2 and is part of a joined publication [4][7][8].

With respect to the Swedish PRISME project a summary of the results can be found in the article presented at the SMIRT conference, which can be found in annex 1.

The major achievements of the Swedish PRISME project can be summarised as follows:

- LTH participated successfully in the benchmark exercises and was part of the joined publication. The results of this benchmark showed the limitation of previous FDS versions for ventilated compartment fires where interaction between fire and ventilation are important. LTH did then a number of successful validations of the new ventilation module developed by NIST. This will create a lot of possibilities for simulation of fire and ventilation flows.

- LTH developed an empirical model for prediction temperature of the smoke gases in a room adjacent to the fire room. This was done by numerical experiments combined with a validation by means of the PRISME results and other large-scale tests. The model worked well for ventilated fires but from the PRISME database it could see that under-ventilated fires do not follow this trend.

PRISME 2

During 2009 and 2010 discussions were made within the project group to work towards an extension of the project. The whole project plan and description is given in Annex 3. The programme of the new experimental PRISME 2 project has been elaborated on the basis of the needs expressed by all members of the PRISME Project and of the conclusions of the Expert Meeting of the OECD PRISME 2 Project held in February 2010. In particular, the members responded that the Project focus will be on fire scenarios of interest in nuclear power plants including multi-compartment fires, ventilation systems, real fire sources with flame propagation, under-ventilated combustion regime and extinction systems. The partners' replies converged towards the three main topics of interest: smoke and hot gas propagation through a horizontal opening between two superposed compartments, fire spreading on real fire sources such as cable trays and electrical cabinets and fire propagation from a fire source to another, and fire extinction studies of the performance of various extinguishing systems. Similarly to PRISME 1 there will be also a number of benchmark exercises performed in a benchmark group. At this stage it is even planned to conduct an open simulation of one of the PRISME project. This information is important to obtain more data in order to determine the uncertainty of CFD simulation tools.

Objectives

The main scope of the Swedish PRISME 2 project is to assess and determine the CFD tools used for fire safety evaluations and to implement the test results from the PRISME project for Swedish applications not only in nuclear power plants but also in buildings and constructions where similar fire scenarios will occur as in the PRISME project.

The objectives are covering three parts:

1. Validation of CFD tools in the scenarios within the PRISME project (mainly FDS but possibly also other CFD tools e.g. Ansys-CFX, Firefoam, ISIS depending on evaluation of the packages). This will be limited to the scenarios and exercises within the PRISME project and will not be an overall validation. In cases where no other experience at LTH is available, other validations, using standard and basic benchmarks, need to be conducted.
2. Dissemination of the test results within the PRISME project to the Swedish fire community by reporting to the reference group in the project, presenting the results at the national seminars and meetings and finally by writing scientific articles.
3. Participate in the benchmark group meetings and other PRISME meetings.

Project Plan

The following activities are planned over a five years period:

1. Use of test results for Swedish Applications.
2. Validation of Ventilation module in FDS with PRISME results.
3. Investigation of other CFD software packages
4. Participation in BE exercises and set-up of a Swedish benchmark exercise.
5. Development and validation of a pool fire model in FDS for enclosures.
6. Dissemination of project results.

The project is divided in 5 work packages:

1. Use of the test results for Swedish Applications

   The PRISME test results are reported by IRSN, France and are part of their reporting obligations to the PRISME consortium. However these results need to be "translated" for Swedish applications. In this work package this information will be gathered.

   In this work package participation to the PRISME meetings is included.

2. Validation of CFD packages by means of the PRISME 2 test results.

   In this work package the validation exercises will be performed. The following activities will take place:

   - Validation of Ventilation module in FDS with PRISME results.

In this activity LTH will further validate the newly developed ventilation module in FDS. This validation will be important for further use of the module in nuclear power plant applications and also building and transport applications.

- Investigation of other CFD software packages

  This activity will look into other CFD packages and how they can be used for performance based design. Possible candidates of software are FireFoam, ISIS and ANSYS- CFX. Choice of the software will depend on availability of resources, both personal and software/hardware.

- Participation in BE exercises and set-up of a Swedish benchmark exercise

  In this work package LTH will take part of the benchmark exercises in the benchmark of the PRISME 2 project. At the moment both blind and open simulation are scheduled and proposed. Especially the blind simulation are important as they will give an important input with respect to uncertainty of simulations due to e.g. unknown pre-knowledge and user effect. This has been clearly demonstrated in a number of previous projects [5] [6]. If blind simulation would not be possible due to insufficient interest in the PRISME OECD NEA consortium, LTH will organise a national blind simulation in which other universities, research institute and consultants can participate.

3. Development and validation of a pool fire model in FDS for enclosures.

   The scope of the WP is to provide improved tools for deterministic evaluation of the risk for loss of functional performance in redundant systems critical for shut down of the reactor within PSA analyses. The improved tool will contain an advanced pool fire model, which takes into account all aspects of the enclosure (geometry, properties, ventilation) and fuel (amount, type, surface area, thermal boundaries).
   Both literature study, development of a pool fire model and validation of the model will be conducted in this work package.
   This WP is part of an approved NKS project with partners from VTT, Haugesund University College and Ringhals AB. NKS is the Nordic Nuclear Safety research foundation (www.nks.org). The first year report has been approved by NKS [9].

4. Dissemination of project results.

   In this work package reporting of the interpretation of the test results as well as the validation exercises will be done. The dissemination will be done by:

   - participation at conferences (e.g. NBSG yearly meeting)
   - seminars (internationally e.g. yearly SMIRT seminar),
   - scientific articles (published as conference proceedings or peer-review articles)
   - SSM or LTH reports

5. Participation in OECD NEA PRISME 2 project

   This work package does not contain activities from LTH or requires financing from Brandforsk but it contains the contribution of Sweden to the PRISME OECD NEA project, which is financed by NBSG. In NBSG all three nuclear power plants are members as well as SKB and SSM. The WP is included in this proposal to give a total overview of the Swedish part of the research project.

Time plan

The time plan for the project is from July 1st 2011 until July 1st 2016. The Brandforsk project will start from June 1st 2012 and end on January 1st 2017. This will allow for a full reporting of the project to Brandforsk.

Budget

The overall project budget for the Swedish part of the PRISME 2 project is 6350kSEK. A breakdown can be found in the table below.

The budget for the Brandforsk project is 250 kSEK per year, totally resulting in 1250 kSEK over a five years period.

The budget is divided as follows over the work packages where WP 3 is the NKS project WP 5 is the contribution to the OECD NEA project.

Work Package	**Budget**	**Requested financing Brandforsk**
1. Use of test results	250 kSEK	250 kSEK
2. Validation of CFD models	750 kSEK	750 kSEK
3. Development and validation pool fire model	1100 kSEK (990 kDKK) from NKS	0 kSEK
4. Dissemination	250 kSEK	250 kSEK
5. Contribution to PRISME 2 OECD/NEA project	4000 kSEK from NBSG	0 kSEK
Total Budget Swedish Part	**6350 kSEK**	**1250 kSEK**
Total PRISME 2 project	70000 kSEK	0 kSEK

Additional committed resources

The Swedish part of the OECD/NEA PRISME 2 project, which finances the experiments at IRSN, is financed by NBSG (National Fire Safety group for nuclear power plants). The Swedish part is 400 kEURO (approximately 4 MSEK) for the whole 5 years period.

Through the NKS project additional resources are available for the Swedish Part of PRISME 2, which focuses another aspect of CFD modelling, namely the development and validation of a pool fire model for enclosures. The overall NKS project has a budget of 990 kDKK (approximately 1100 kSEK) for a three-year period. The LTH budget in this project is 450 kDKK (approximately 500 kSEK).

The budget in this application would support the important validation and dissemination activities.

It is also important to note that the overall value of the PRISME 2 project is about 70 MSEK (7 MEuro)

Project group

The project group is composed as follows:

- Patrick van Hees, professor at Lund University, Department of Fire Safety Engineering and Systems Safety, project leader, responsible for WP 1 and 3, project leader for WP4.
- Jonathan Wahlqvist, PhD student at Lund University, Department of Fire Safety Engineering and Systems Safety, responsible for WP 2
- Simo Hostikka, VTT Finland (WP 4 as part of the NKS project)
- Bjarne Husted, Haugesund University College (WP 4 as part of the NKS project)
- Tommy Magnusson (WP 4 as part of the NKS project and Swedish representative in the OECD NEA project, responsible for WP 5)
- Fredrik Jörud (WP4 as part of the NKS project)

At the moment, the following countries will participate in the project group for the PRISME2 project:

- Belgium
- Canada
- Finland
- Germany
- Japan
- Spain
- Sweden

Collaboration between the partners of the PRISME OECD/NEA project and the Swedish project group will be envisaged during the whole project. Also cooperation within the NKS project will be obtained. Amongst the participants there is also Simo Hostikka, one of the FDS developers. This will give the project a direct connection to the FDS development group.

Benefit and Beneficiaries of the project

There are a number of benefits of the project:

1. Information on the capabilities and limitations of CFD calculation tools for fire and smoke spread in under-ventilated conditions are important for different areas such a nuclear power plants, buildings, transport and energy storage.
2. The further validation of the ventilation module in FDS will be of great benefit for areas outside nuclear applications, as it would give the opportunity to run a fire simulation, which includes the ventilation system. Earlier other programmes needed to be used. It will as such also improve efficiency of fire safety calculations for ventilation systems in buildings.
3. The tests include important information on under-ventilated fires with respect to cables fires, sprinkler fires and pool fires.
4. The improvement of pool fire models is of importance for industrial applications.

Beneficiaries for the project are industry (power industry, building industry, transport), consultants, governments (Boverket, SSM, MSB) and other research institutes and universities.

Dissemination of the results

Dissemination of the project is an important part. Due to the internal rules of OECD/NEA all results are confidential for a period of 5 years.

The Swedish reports will be available through SSM, Swedish Radiation Safety Authority, at the end of the project. However in order to increase the dissemination, an extra route will be used. Publications on the project achievements can be published in international journals if the consortium agrees about this. In many cases this has not been a problem during the PRISME1 project and the Swedish project group will also use this route to speed up publication internationally.

Annexes

Annex 1: Summary of the Swedish part of PRISME 2 through a research article to be presented at the SMIRT conference in September 2011, submitted September 1st.

Annex 2: Results of the first benchmark exercise in PRISME1, publication of Nuclear Engineering

Annex 3: Project description of the OECD/NEA PRISME 2 project

Note: Other open reports from PRISME 1 are available through the applicants, Brandforsk or NBSG.

References

[1] Http://Www.Oecd-Nea.Org/Jointproj/Prisme.Html, Information of the PRISME Project, Downloaded June 2011 .

[2] Rigollet L, Röwekamp M. Collaboration of fire code benchmark activities around the international fire research program PRISME. Proceedings of EUROSAFE, Brussels 2009;2(3.11).

[3] Klein-Heßling W, Nowack H, Spengler C, Weber G, Höhne M, Sonnenkalb M. Cocosys--New modelling of safety relevant phenomena and components. .

[4] Audouin L, Chandra L, Consalvi JL, Gay L, Gorza E, Hohm V, et al. Quantifying differences between computational results and measurements in the case of a large-scale well-confined fire scenario. Nuclear Engineering and Design 2010.

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[6] Holmstedt G, Bengtsson S, Blomqvist P, Dittmer T, Hägglund B, Tuovinen H, Van Hees P. Kvalitetssäkring av olycks-och skadeförebyggande arbetet med brandskydd i byggnader. 2008.

[7] van Hees P., Johansson N., Wahlqvist J., Swedish PRISME project – Part 2 - Use of test results from PRISME for practical applications in Sweden, Report 3155, ISRN: LUTVDG/TVBB--3155—SE, Lund 2011.

[8] van Hees P., Wahlqvist J., Swedish PRISME project – Part 4 – Results of benchmark exercises at LTH, Report 3157, ISRN: LUTVDG/TVBB--3157—SE, Lund 2011.

[9] van Hees P., Wahlqvist J., Hostikka S., Sikanen T., Husted B., Magnusson T., Jörud F., Prediction and validation of pool fire development in enclosures by means of CFD (Poolfire) Report – Year 1, ISRN: LUTVDG/TVBB--3163—SE, Lund 2012.

VALIDATION AND DEVELOPMENT OF DIFFERENT CALCULATION METHODS AND SOFTWARE PACKAGES FOR FIRE SAFETY ASSESSMENT IN SWEDISH NUCLEAR POWER PLANTS

Patrick van Hees[1], Nils Johansson[1], Jonathan Wahlqvist[1], Tommy Magnusson[2]

[1] Lund University, Department of Fire Safety Engineering and Systems Safety, Sweden

[2] Ringhals AB, Sweden

ABSTRACT

Fire models are used increasingly for fire safety assessment in nuclear power plants. Examples of these fire models are CFD models and zone models. When using these models it is important that they are sufficiently verified and validated. In Sweden the majority of fire safety consultants are using FDS, developed by NIST. The verification and validation of this package is intensively done for a number of scenarios by the developing team. One of the recent modifications in FDS is the implementation of a ventilation module. The first aim of this paper was to validate FDS and ANSYS-CFX within the Swedish part of the OECD/NEA PRISME project using the PRISME SOURCE D1 test. The results are presented in this article and show how powerful the module is for simulation in enclosures with mechanical ventilation. Beside CFD models, fire safety engineers need also simple empirical models for determining temperatures, smoke heights, etc. In the second part of this paper such a model is developed. The model predicts gas temperatures in a room adjacent to a room involved in a pre-flashover fire. The correlation is derived with help of computer simulations and validated by means of a set of fire tests. The results of the correlation model are satisfactory and the correlation formulae will be an additional tool for fire safety engineers.

INTRODUCTION

Validation of CFD Models

The partners participating in the international OECD/NEA project PRISME [1] investigated the use of CFD and zone models for enclosures with mechanical ventilation. This was performed in the benchmarking group. The main PRISME program (French acronym for "Fire Propagation in Elementary Multi-room Scenarios") mainly aims on studying smoke and hot gases propagation in full scale, well-confined and mechanically ventilated fire compartments [2]. In particular, the goals of the PRISME program are to understand and quantify, by means of an analytical approach, the propagation mechanisms of smoke and heat from a fire compartment towards one or several adjacent compartments in scenarios representative for nuclear plants. For this purpose one of the tests was used in an open validation exercise (a posteriori), namely the PRISME SOURCE D1 test. The exercise was performed in the PRISME consortium and reported by Audouin et al. [3] and contained validation of different zone, hybrid and CFD models. The test set-up and overview of the test rig used for the test are given in Figure 1. All the FDS results reported by Audouin et al. were based on the boundary conditions available in FDS [4] [5] at that moment, which did not have the possibility of using the most recent ventilation module developed by Floyd. This paper will report how this ventilation module in FDS have been used and applied on the PRISME SOURCE

D1 tests. Moreover, results with the commercial software ANSYS CFX [6] are also given for the same test set-up. Further details about the test can be found in the publication from the benchmark exercise [3].

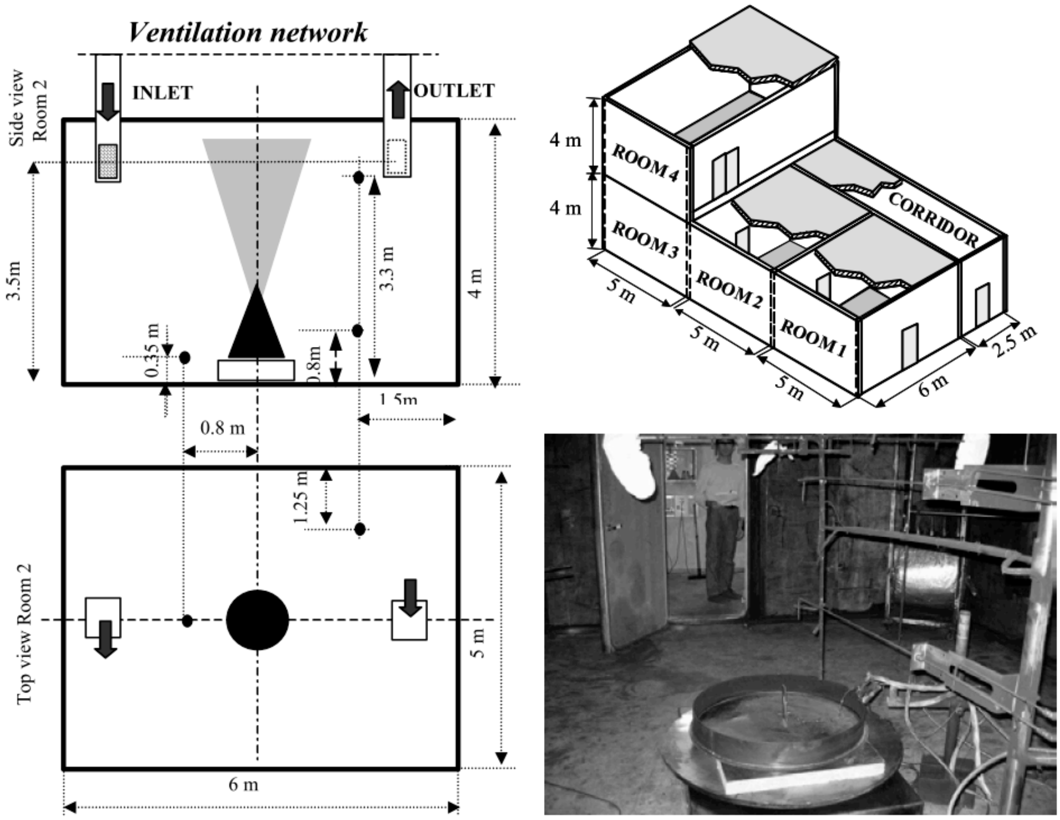

Figure 1 Overview of the experimental setup (courtesy to IRSN)

Use of Empirical Models

Advanced computer modeling software that can predict smoke spread and compartment temperatures has been developed during the last decays. With zone models and computational fluid dynamics (CFD) it is possible to e.g. calculate smoke layer heights, species and temperatures in a multi-room geometry. The programs are generally good tools for fire engineering purposes, but they do not remove the need for simple engineering correlations. Simple correlations can be used for hand-calculations to get a first estimate of e.g. smoke layer temperatures in performance based design of a building and help the fire engineer to determine if it is necessary to perform a detailed CFD calculation. Simple correlations can also be a useful tool to use in sensitivity analysis or in fire risk analysis.

Correlations that predict compartment temperatures for single room enclosures date back to the early eighties [7], [8] and are still used for different purposes by fire engineers. These correlations are rough and less accurate compared to computer simulations but they have the benefit of being simple and giving a good description of the hazard. The method that McCaffrey et al. presented [7] (MQH-correlation) is based on a simple conservation of energy expression. The MQH correlation gives the gas temperature as a function of the heat release rate, ventilation conditions, enclosure geometry and thermal properties of the enclosure. The MQH correlation has a set of limitations, which the user must be aware of, but it has been shown to give good predictions of room fire temperatures [9]. The correlation has even been developed further and modified [8], [9]. Lately new models for predicting compartment fire temperatures have been presented [10], [11]. However there are few correlations that can predict temperatures outside the room of fire origin. Thus such predictions have to be done with the help of zone or CFD models. A simple correlation that would predict temperatures outside a compartment is something that could be useful to get a first estimate when for example evaluating conditions for evacuees in a room next to the room of fire origin or to make a first assessment with respect to functional performance of cables.

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METHOD

Validation of CFD Models

The experimental scenario (Figure 1) was conducted at the French "Institut de Radioprotection et de Sûreté Nucléaire" (IRSN). The quantitative comparisons between measurements and numerical results obtained from "open" calculations concerned six important quantities from a fire safety viewpoint: gas temperature, oxygen concentration, wall temperature, total heat flux, compartment pressure and ventilation flow rate during the whole fire duration. The fire source [12] consisted of a 0.4 m^2 steel pan filled with hydrogenated tetra propylene (TPH), an isomer of n-dodecane. The walls, ceiling and floor of the room were 30 cm thick and made out of concrete. During the experiment, rock wool (THERMIPAN) with a thickness of 5 cm insulated the ceiling to prevent damage to the facility. The ventilation system in the fire room included an inlet branch and an exhaust branch, the relative static pressures and volume flow rates was recorded before the fire was ignited and was later used as input data in FDS simulations [13] [4] and for ANSYS-CFX [6].

Use of Empirical Models

The work presented in this paper has been performed in three steps. In the first step numerous CFD simulations with the computer software FDS 5 [4] have been conducted. Input files to FDS, with randomly sized two-room configurations, were created with a Matlab script. Approximately 140 FDS files were simulations with different, geometries, openings, wall materials, fuels and heat release rates on the Lund cluster. In all simulations the fire was placed in the center of the fire room as illustrated in Figure 1.

The various inputs are e.g. size of the door-opening, size of the room, HRR, fuel, properties of the wall and wall thickness. The mesh size was determined by following the recommendations of characteristic fire diameter D*, which varied between 0.61 and 1.27 m. In the second step a statistical analysis has been conducted with the statistical software package SPSS (Statistical Package for the Social Sciences) [14]. The smoke layer temperature in the adjacent room was retrieved from the FDS simulations and was used as dependent variable in the statistical analysis. The heat release rate, area of boundary surfaces of both enclosures, ventilation factors for both openings and heat transfer coefficient were used as independent variables. A multiple linear regression analysis of the logarithmic values of the variables were conducted in SPSS.

In the third step the correlation was tested and validated against results from full-scale experiments both found in literature and conducted within the project.

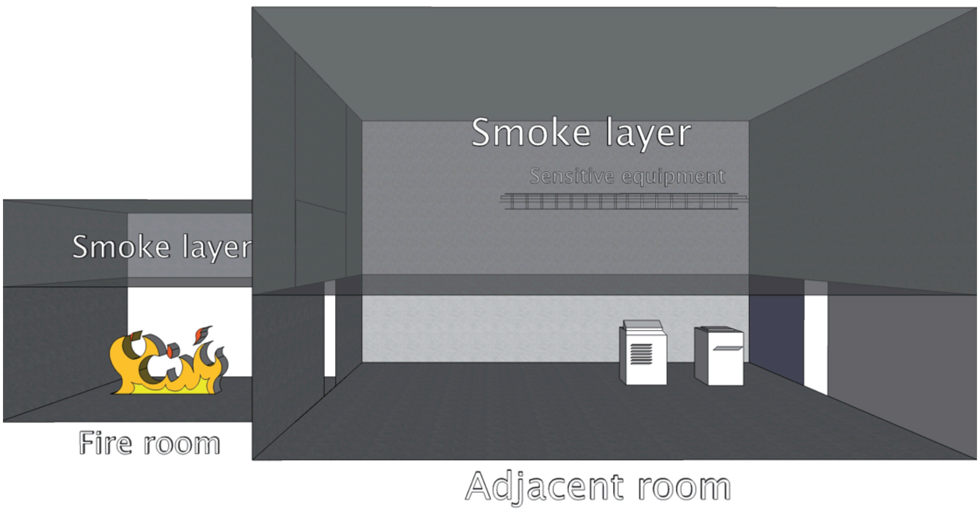

Figure 2 Room set-up for the simulations

RESULTS AND DISCUSSION OF THE VALIDATION OF THE VENTILATION MODULE

The leak area from the fire room to surroundings was calculated using data from PRISME SOURCE – Ventilation Tests. Leakage between the fire room and surroundings was assumed to be a quadratic function of pressure difference. The calculated total leakage area from the fire room was in the order of 4 cm^2. The sensitivity of this parameter was tested by doing two more calculations with FDS, one with zero leakage, and one with 10 cm^2 leakage. As seen in Figure 3, the impact is quite large. When changing the total leakage with 4 – 6 cm^2, the first pressure peak in the experiment changes in the order of 50 Pa.

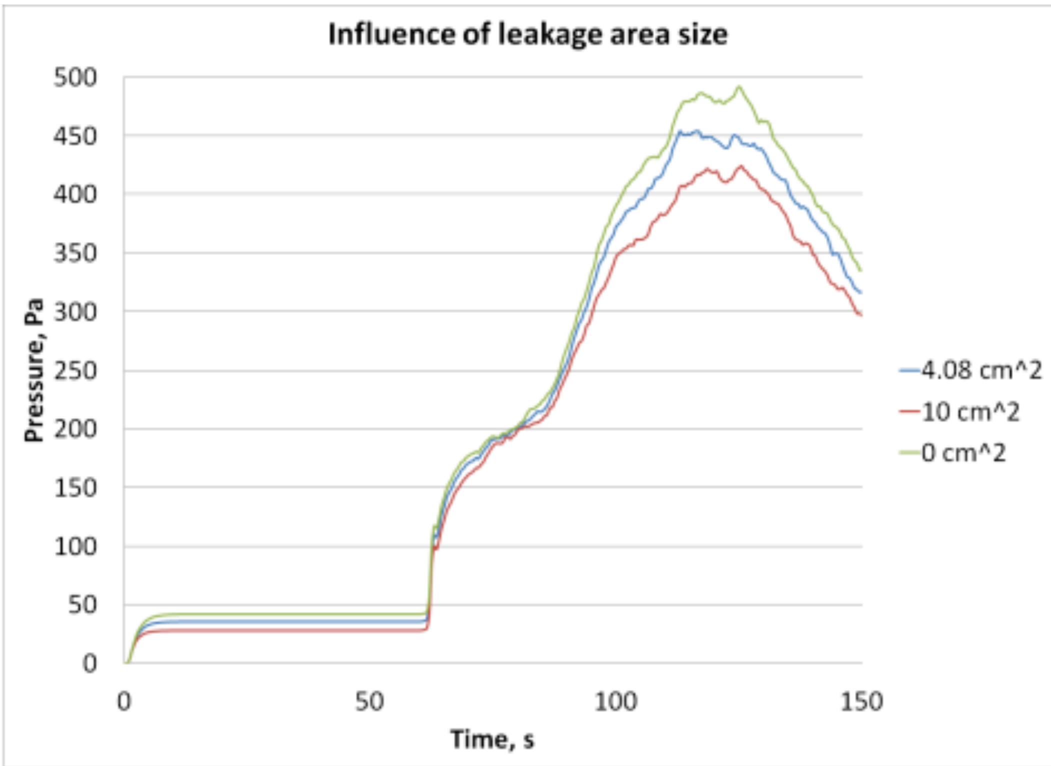

Figure 3 Influence of changing the room leak area in FDS

The geometry used in the simulation can be seen in Figure 4. Since the full ventilation system (Figure 5) was modeled with FDS, it was necessary to compare the experimental data in every node of interest with the data produced with FDS, prior to the fire being ignited. If this proved to give a good prediction, the likelihood of getting good results when compared to the full experiment would be far larger. As can be seen in Table 1, the results agree very well with the experimental data. Only one node shows a relative pressure difference larger than 10%, though the pressure difference is only about 40 Pa.

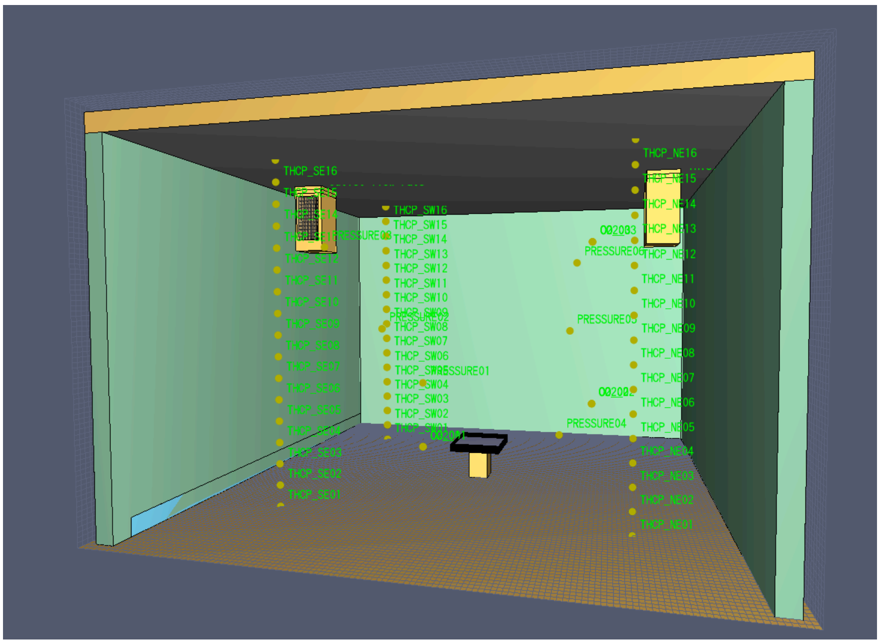

Figure 4 Geometry for the simulations with ventilation module

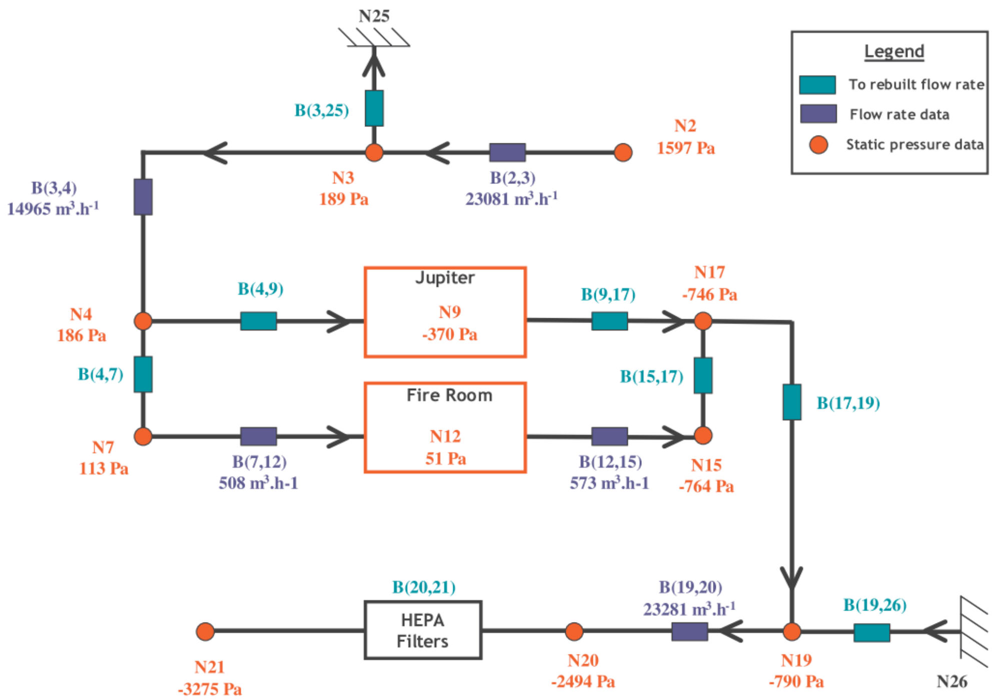

Figure 5 Layout of the ventilation network (courtesy to IRSN) and a comparison between FDS data and experimental data

	N2	N3	N4	N7	Fire room	N15	N17	N19	N20	N21
FDS, Pa	1575.73	191.71	188.81	162.77	35.5	-706.71	-726.09	-769.46	-2446.5	-3228.18
Experiment, Pa	1597	189	186	113	37.9	-764	-746	-790	-2494	-3275
Difference, %	1.33	1.43	1.51	44.04	6.33	7.50	2.67	2.60	1.90	1.43

Table 1 Comparison of FDS5 results and measured pressure in each ventilation node (courtesy to IRSN)

An overview of the temperatures calculated with both CFX and FDS compared to the experimental data can be seen in Figure 6. FDS manages to give a good prediction of the temperatures (within 10 – 15 %) on a relatively coarse grid (10 cm cubes), providing a good basis for evaluating the ventilation system behavior. Unfortunately the same cannot be said about CFX. CFX over-predicts the temperature by far (30 – 50 %), however, it cannot be ruled out that errors made by the software operator influences this deviation. Also, the way CFX handles combustion, for example internally calculating heat of combustion, prevented use of the experimental value obtained. This will likely impact the temperatures in the fire room. Also, heat transfer to the surrounding walls has been taken into account, but it was unclear if it was properly set up even though initial tests were performed.

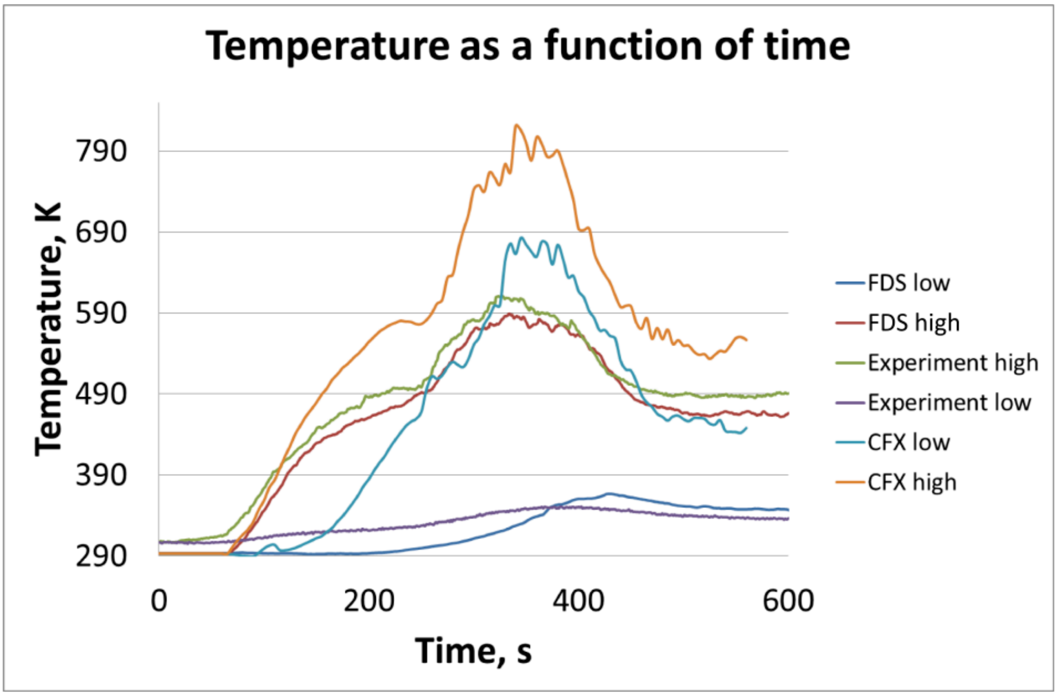

Figure 6 Temperature (highest and lowest measure point) as a function of time for the first 600 seconds

Since full capabilities concerning ventilation system modeling is not present in CFX (simplifications were made at the in- and outlet branch, specifying appropriate boundary conditions to get realistic pressures in the fire room), only results from calculations made with FDS are presented when comparing pressure in fire room and mass flow in the ventilation branches. As seen in Figure 7, the calculated pressure in the fire room is very close to the experimental data. All pressure peaks are fairly well predicted, and this is using only data available prior to the fire being ignited (except for HRR).

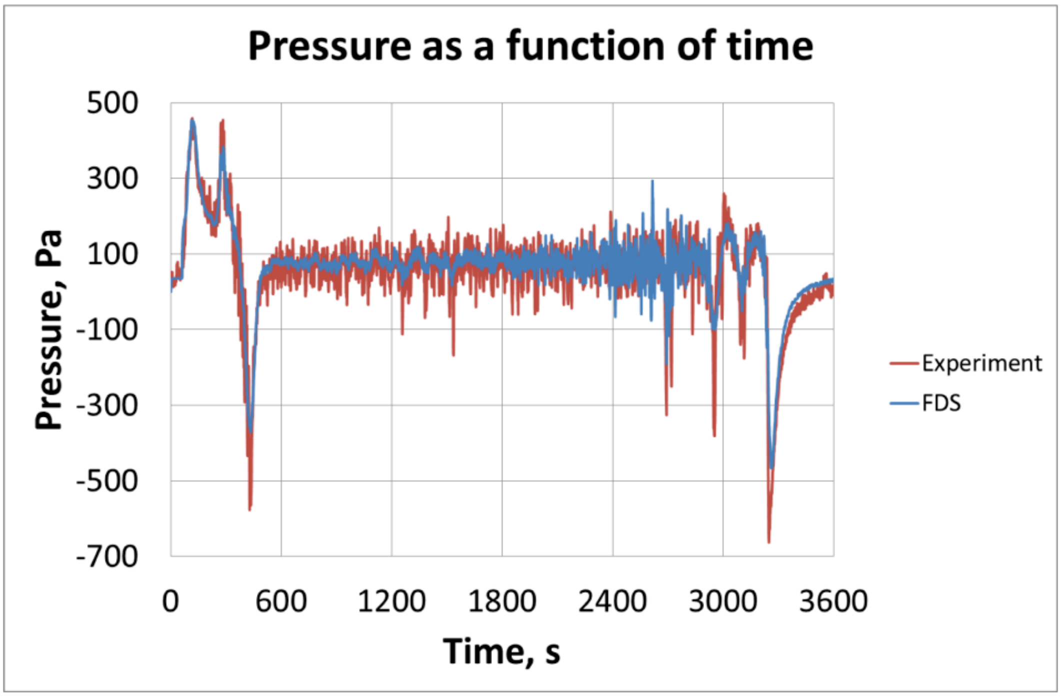

Figure 7 Pressure in the fire room as a function of time

Looking at the inlet and outlet branches (Figure 8) it is shown that FDS manages to predict the backflow in the inlet branch correctly. However, due to differences in the reported data from the experiment (actual measured mass flow not the same as reported in figure 3), the mass flow at the in- and outlet before the fire was ignited does not correspond to the FDS values. This in turn affects the "steady-state" mass flow in the later part of the experiment (after 600 seconds) making the FDS prediction somewhat incorrect. But it can be seen that the difference is constant, indicating that with the right starting values, FDS would give a better prediction.

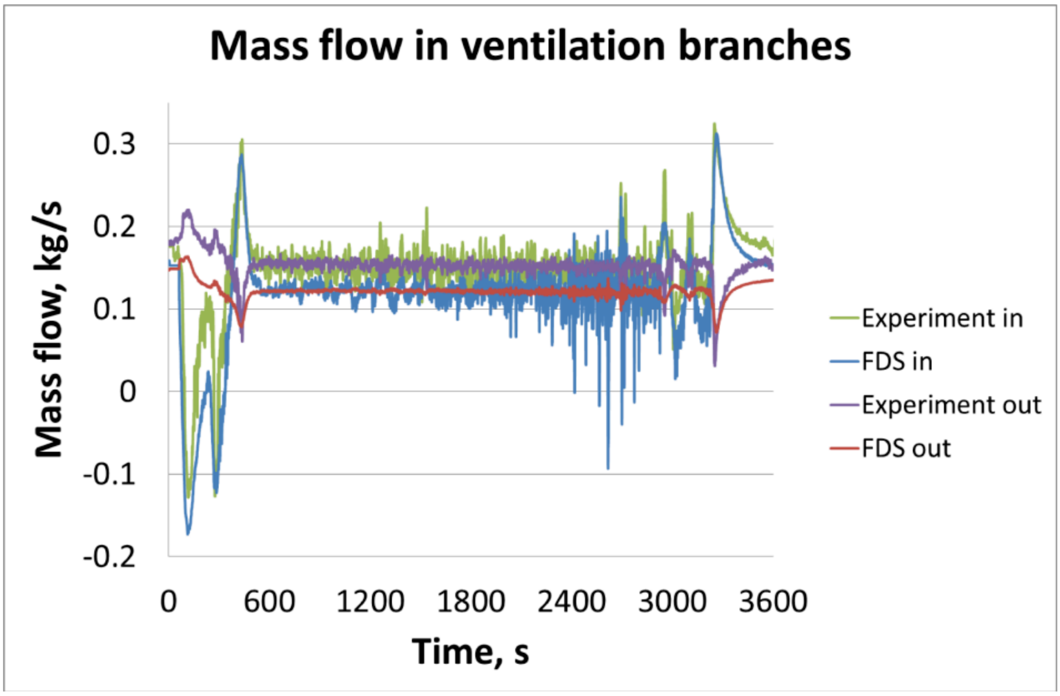

Figure 8 Mass flow in the ventilation branches as a function of time during the experiment

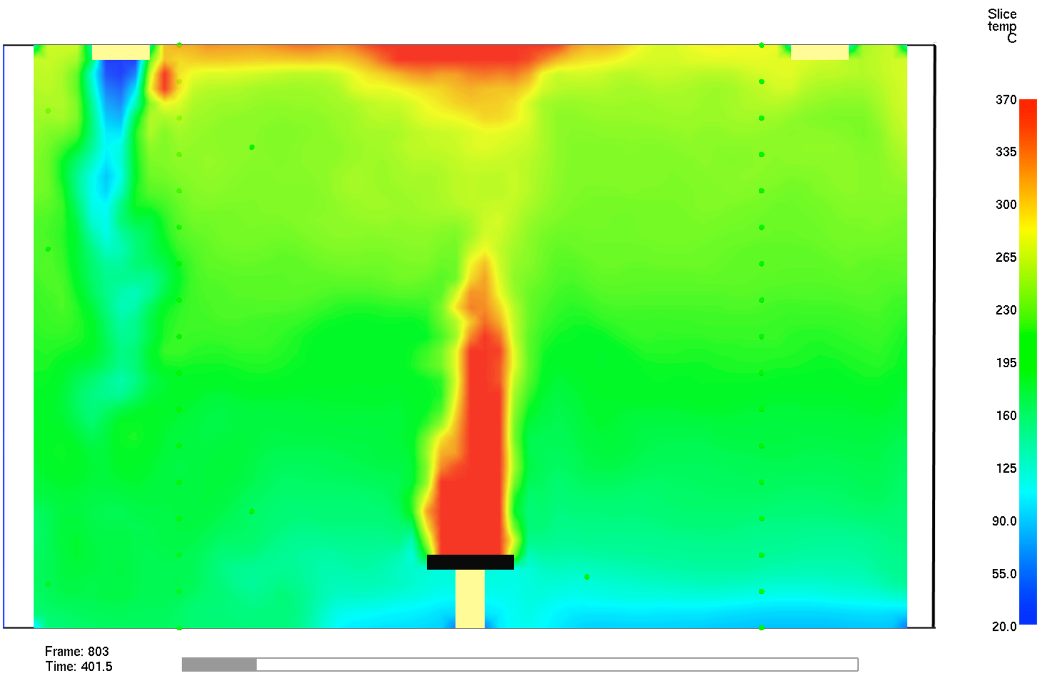

Figure 9 Snapshot of a temperature slice during the simulations done with FDS5. The incoming cold air is clearly visible at the top left corner

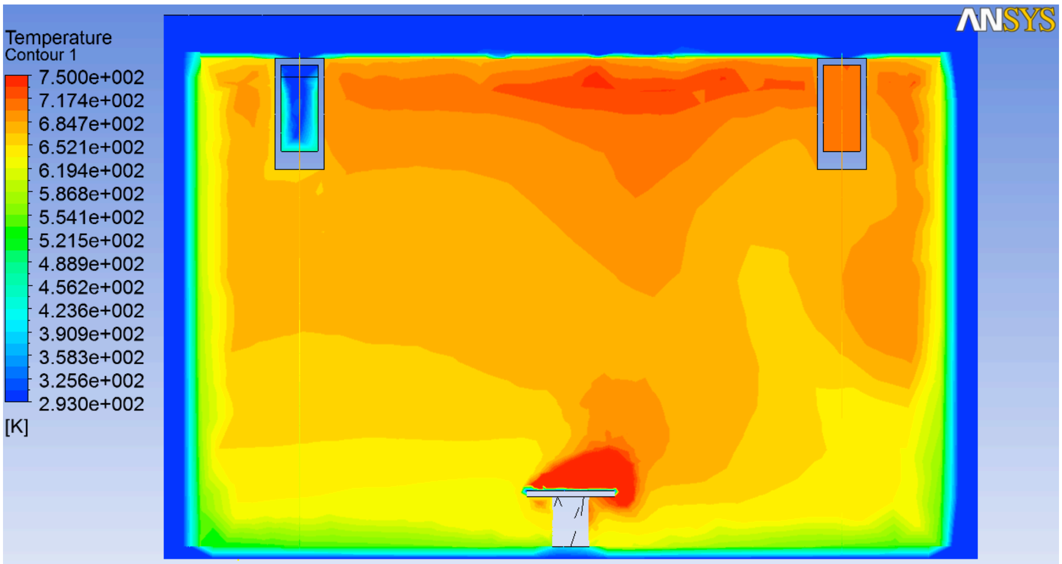

Figure 10 Snapshot of a temperature slice during the simulations done with CFX

In Figure 10, the incoming cold air is clearly visible at the top left corner. It can also be seen that the temperature gradient from ceiling to floor is not as steep as shown with FDS5. The maximum temperature is also overestimated to a quite large degree.

RESULTS AND DISCUSSION OF THE DEVELOPMENT OF THE EMPIRICAL MODEL

All included variables were statistical significant and the correlation had a correlations coefficient, R2-value, of approximately 0.9 with respect to the data from the simulations (Figure 11). The most important variable was the heat release rate. A validity check was performed by studying data from real fire tests [15], [16]. Three sets of experimental data were studied and the result of the validity check can be found in Figure 12. It is considered to be a good agreement between the calculated and measured temperatures since the maximum difference is less than 20 %.

A reliability check was performed by looking at the grid sensitivity of six of the preformed simulations, when decreasing the grid size from 0.1 to 0.05 m. The presented work is based on FDS simulations of well-ventilated pre-flashover fires. Thus the results are only valid for such conditions. This could be seen when adding the PRISME data in the correlation, which turned out to be outliers.

The method used to find a simple correlation for temperatures in the room adjacent to the fire room was very successfully and could possibly be applied to other areas in fire science to be able to find other simple correlations that can be used by engineers in an initial stage of their design. Some more experimental data is necessary to fully validate the developed empirical formulae and it should be investigated how the formulae could be adapted for under-ventilated conditions. This is not the case for the moment as could be seen from the data obtained via the PRISME project.

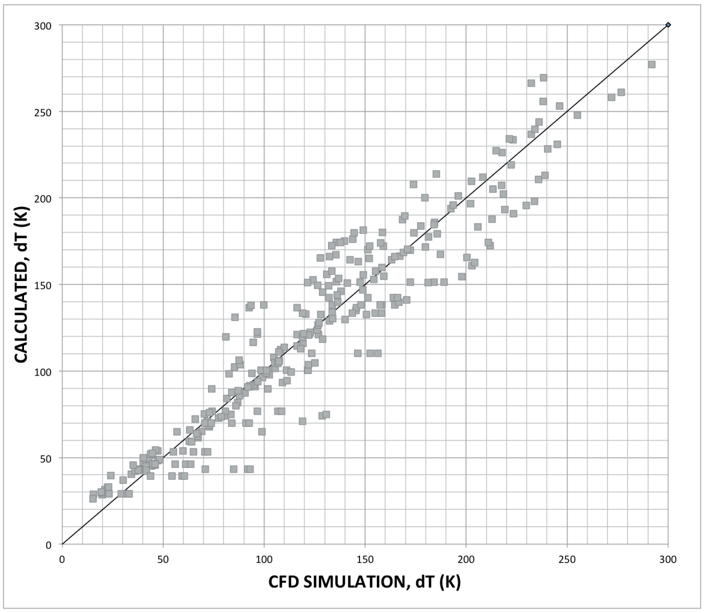

Figure 11 Correlation graph between calculated and simulated temperature increase

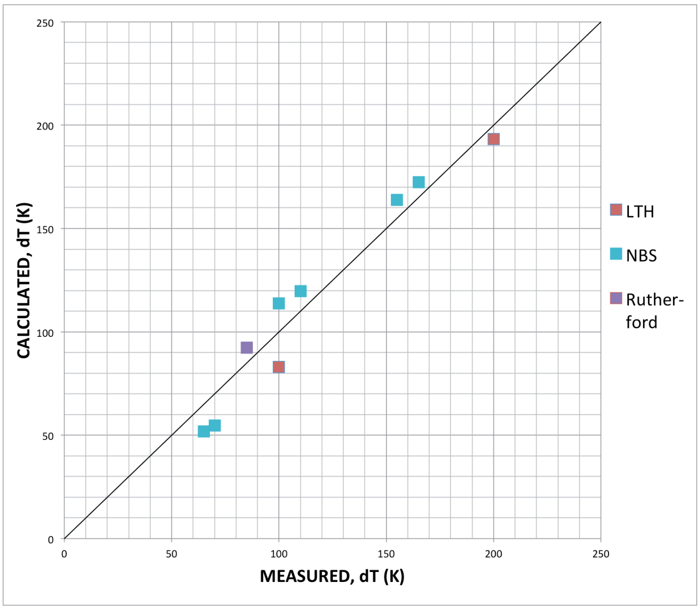

Figure 12 Comparison between calculated and measured temperature increase (only ventilated fires)

CONCLUSIONS

In this paper two activities within the Swedish PRISME project were summarized. One reports on the development of a simple empirical correlation for temperatures in the room adjacent to the fire room. The development was done by numerical experiment technique and validated against a first set of test data. The results are satisfactory and further validation will be done. Application of the models is not only within fire safety design of nuclear power plants but also in traditional buildings. Another activity was the validation of the newly developed ventilation module in FDS against the PRISME Source D1 tests. The results of this validation show that the module is working properly and give satisfactory results. The intention is to validate the model against more data in PRISME project database and to implement the module in a realistic fire safety design of a traditional building where mechanical ventilation is involved.

The activities of the Swedish PRISME project, which were initiated by the nuclear industry and government in Sweden, show clear spin-off to other fire safety areas such as traditional buildings and other industrial applications.

ACKNOWLEDGEMENTS

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The other project is called "Varför blir små brander stora?" (Why become small fires large) and is financed by The Swedish Fire Research Board (Brandforsk) and NBSG (the Swedish NPPs Fire Safety Group). The purpose of the project is to find underlying factors to why some fires grow large.

Finally the authors would like to thank IRSN in order to provide them information about the technical details of the ventilation system which was used when IRSN performed the fire tests in the PRISME project.

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