Tommy Hertzberg
Björn Sundström
Patrick van Hees

# Design fires for enclosures
**A first attempt to create design fires
based on Euroclasses for linings**

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# Abstract

In the quest to develop more fire safe environments, the design fire is a crucial and decisive parameter as it is used to predict fire development in a given enclosure. The methods used today are often based on some very broad and general descriptions of fires in a multitude of possible fire scenarios. No simple tools for predicting more differentiated fire scenarios exist and the only possible modelling resources today for complicated fires and geometries are CFD-based tools that require both high performance computers and  highly trained users.

In this report, we describe easy-to-use methods and models for creating design fires that are much more able to handle more precisely defined geometries and ignition sources then earlier design fire models. In particular, we present models and simulation tools that use experimental data from a small scale standardized test method, ISO 5660 Cone Calorimeter method, to characterise the fire behaviour of materials. We show in this report how the small scale data from a particular surface lining material can be used to simulate fire evolution in a full-scale environment. Further, the utility of Cone Calorimeter data for creating design fires based on the newly established Euroclass system for surface linings is shown.

We demonstrate the usage of both a semi-empirical model that simulates the intermediate-scale EN 13823, SBI test method and the ISO 9705 full-scale Room-Corner Test, and a 2-Zone model that incorporates flame spread modelling.

Key words: Design fire, fire safety engineering

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# Preface

# Summary

Performance-based fire safety engineering (FSE) is an important tool for creating fire safe environments. However, much of the necessary information for using the FSE tool efficiently is today either lacking or poorly understood. An important part of FSE is the assumed fire growth for the environment in question. Many uncertainties in FSE are related how close the model fire can get to a real situation. This model fire is frequently called 'the design fire'.

Previously, the design fires used have been based on some very general, heuristic concepts of fires and fire environments, e.g. 'fast fire, slow fire' and 'official buildings, private buildings'. The models describing the fire evolution were based on a simple quadratic time-function that provided a fire Heat Release Rate (HRR), $Q$, e.g.:

$$Q = \alpha t^2$$

It is obvious that such a simple model is insufficient when describing complex fire scenarios.

Recent development of fire models and increased computing power has made more realistic fire simulations possible. Fire spread models that use small-scale experimental data from the ISO 5660 Cone Calorimeter method, have been incorporated into simulation tools of various complexities. The method is promising as the experiments provide basic information on the material behavior that is difficult to obtain through other means. Also, there is a great deal of Cone Calorimeter data available and collecting new data is a fairly cheap and quick thing to do.

Using the particular fire characteristics of materials as input data to models, instead of describing the general 'hotel' or 'small enclosure' fire, obviously permits a much more differentiated picture of the fire evolution, which in turn permits a more detailed picture for FSE. Furthermore, if a more general description is desired, e.g. for estimating the potential effect of choosing a Euroclass B, C, or D lining in a given enclosure, simulations are easily made by using averaged Cone Calorimeter data for materials from these different classes. In fact, any 'typified' fire behavior based on a material group behavior is possible, provided sufficient Cone Calorimeter data are available.

In this report we demonstrate the use of a semi-empirical model, 'Conetools', developed at SP-Fire technology, Borås, that simulates the intermediate-scale EN 13823, SBI test method and also the ISO 9705 full-scale Room-Corner test, based on input data from the ISO 5660 Cone Calorimeter test method. We further demonstrate the concept in a 2-Zone model that incorporates the option of flame spread modelling from Cone calorimeter data. The simulation tool, BRANZfire, was developed at the Building Research Association of New Zealand.

A number of different test cases have been simulated and comparisons made between simulated results and experimental data from the intermediate-scale (SBI), full-scale (Room-Corner) and different large-scale fire scenarios. We also compare the results from the design fires obtained with the suggested method, to some results obtained with the earlier approach for creating design fires. It is seen that even though the results from the new method often can be described as a subset of the older methods (which seems logical since the older method must use a certain amount of 'over kill' in order to cover all possible cases), we also found examples of situations where the older methods seems to underestimate the fire hazard.

We further presents in this report some experimental data from fires involving electrical cables and electronic equipment, as well as some data from train compartment fires. These experiments have not been compared to simulations by the suggested methods but could very well be tested against similar models and simulation tools. It is our intention to do such work in the future and also to demonstrate the efficiency of using Cone calorimeter data for flame spread modelling also for field model simulations, i.e. using CFD-codes.

# 1 Considerations for the design fire

## 1.1 The present way of creating a design fire by the default method

Performance-based fire safety engineering (FSE) is an important tool for creating fire safe environments. The efficiency of such a tool depends on information from several disciplins, such as human behavior in fires and, of course, the nature of the fire itself. However, much of the necessary information for using the FSE tool efficiently is either lacking or poorly understood [1].

A fire hazard analysis relies on assumptions about fire growth that are made by the engineer. The time scale for the fire depends on the selection of the design fire and this time scale will in most cases determine the time for further fire spread, the probabilities for casualties, the time available for escape and so on. Therefore, the method used to arrive at a plausible design fire has been the object of much research over the years. However, methods that are used internationally are still rather crude and need to be further improved to be more versatile. We find methods to develop a design fire in ISO documents and as an example we will look at Nordic regulators recommendations.

ISO/ TC 92 Fire Safety, SC 4 Fire Safety Engineering, is working on a series of documents covering the topic of fire hazard (ISO TR 13387-13394) [2,3,4,5,6,7,8,9]. These documents are written in very general terms leaving the interpretation of the documents to the consultants. In the document ISO TR 13388 Fire Safety Engineering-Design Fire Scenarios and Design Fires, the philosophy of creating a design fire is emphasized rather than actual examples of how to create a design fire. It is recommended that statistics for the building and occupancy under consideration are used to identify the most likely types of fire scenario. This is done using information of most common item ignited, ignition source and location of fire. The design fire is chosen from the most likely scenario having the highest fire hazard; the worst credible case is used. However, fire statistics are far from complete, and engineering judgment must therefore be used.

The design fire should be chosen very carefully, but there are only occasionally tangible proposals. The most frequently suggested design fire is the $t^2$- fire where the heat release rate is described by $Q = Q_0 \left( \dfrac{t}{t_g} \right)^2$ , where $Q_O$ is normally chosen to be 1 MW. The recommendations of $t_g$ are 600, 300, 150 and 75 seconds for *slow*, *medium*, *fast* and *ultra fast* fires respectively.

In Annex A in ref. 3 proposals for $t^2$- fires are given for various design fire scenarios, see Table 1.

**Table 1      Design fires as given in ISO TR 13388.**

| Design fire scenario | Category |
|---|---|
| Upholstered furniture and stacked furniture near combustible linings | *Ultra fast* |
| Light- weight furnishings | *Ultra fast* |
| Packing material in rubbish pile | *Ultra fast* |
| Non- fire retarded plastic foam storage | *Ultra fast* |
| Cardboard or plastic boxes in vertical storage arrangement | *Ultra fast* |
| Office furniture- horizontally distributed | *Medium* |
| Displays and padded work- station partitioning | *Fast* |
| Bedding | *Fast* |
| Floor coverings | *Slow* |
| Shop counters | *Medium* |

Nordic regulators have published a document that assigns a design fire as a function of type of occupancy. This was inside a committee called NKB, "Nordic committee on building regulations". NKB [10] gives a selection of design fires depending on the type of building, see Table 2.

**Table 2      The NKB design fires.**

| Category of use | $\alpha$ (W/s$^2$) |
|---|---|
| A (dwellings) | 12 |
| B (hotel) | 50 |
| C (shops, public spaces) | 190 |
| D (schools, offices) | 50 |
| E (industry of large fire hazard) | Not applicable |

The design fire is expressed as $Q = \gamma_q \alpha t^2$ where Q is the HRR, $\alpha$ is given above, t is time and $\gamma_q$ is a partial coefficient. There are no recommendations on how to use the partial coefficient. This expression gives the same result as the earlier mentioned formula $Q = Q_0 (t/t_g)^2$.

For the purpose of this report we call the discussed methodology to create the design fire, the *default method,* as the input data and criteria for selection of a certain design fire is at best based on generalization of fire behavior data and fire statistics. At worst it is closer to a pure guess.

The default method of creating the design fire is depicted in Figure 1 below.
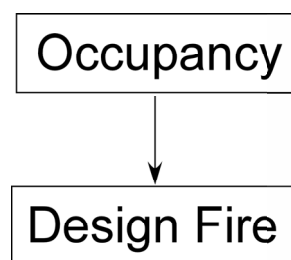


**Figure 1      The present way of creating the design fire by the default method.**

It is seen from the figure that the resulting design fire is arrived at directly as a result of selecting the occupancy. There are of course cases when some calculations take place, but the default procedure does not require that, as the fire growth rate is already given by the default curves. The maximum HRR of the design fire must of course be defined, as it cannot grow indefinitely. This is often done by calculating the limit for ventilation control, sprinkler action etc. However, adding information of the characteristic fire properties of the products involved in the fire would add considerably to the accuracy of the resulting design fire assumption, especially for the early stages of the fire. Product specific data that are representative of groups of products are necessary to make this possible. We will consider the building products as well as the building contents in this respect.

## 1.2      Building content

Furnishing, beds and to some extent large drapes are prime sources of fire growth in buildings. Especially upholstered furniture and beds appear in fire statistics as prime sources of causalities in dwelling fires. These products are discrete items in the building and do not extend over large areas like linings. Therefore, from the characteristic fire growth point of view, we consider them as point sources with respect to the extension of the fire. They would typically serve as an ignition source of other furniture items or wall linings. They may also be powerful enough sources to cause a large fire by themselves. In any case, we can characterise the fire growth on these products by using the HRR curve from a complete burning item. Data from the Furniture Calorimeter can be used for the specific item or, more practically, generic data from product groups based on results from a database or statistical data on burning behaviour. The technique is described in reference [29]. TV-sets and other home electronics are also considered as the building content for the purpose of this report. They are considered as point sources and their characteristic fire growth is handled in a manner similar to that of furniture.

## 1.3      Linings

The characteristic fire growth of linings cannot be regarded as a point source in contrast to items of furniture, TV-sets, home electronics or other appliances. The fire growth in a lining is largely driven by flame spread over large surfaces. Therefore there is no way to characterise a lining by the HRR curve of a complete item like a chair or a TV. Further, the fire growth on a lining is dependent on the space where the fire is taking place. The size of the room, the number and location of openings play an important role for the fire growth on a lining. Also the position in the room is important: fire spread on the floor will be different from the fire on the ceiling and so on. Therefore, there is no such thing as a characteristic fire growth of a wall since the actual HRR and flame spread occurring in a real situation, is dependent both on the fire characteristics of the material in question and on the environmental conditions. This means that we have to decouple the environmental influence of the HRR curve and find data that are based on material properties only. To obtain such data we select the Cone Calorimeter [12] apparatus.

The Cone Calorimeter output is the HRR from a small sample (10x10 cm) exposed to a uniform heat flux that is normally selected to be 25-50 kW/m$^2$. The test is an ISO standard (ISO 5660) since many years and a wealth of experience and information on the test procedure is available worldwide. The Cone Calorimeter is also a prominent candidate to be a standard method for use in fire safety engineering. Much test data is available at SP-Fire Technology from the Cone Calorimeter. There is also data available from large-scale tests like the Room/Corner Test and other room configurations from the

same products. Also the official classification according to the Nordic system and the forthcoming Euroclass-system for the same products is often known. Therefore, if a useful method is designed that characterise the typical fire growth due to linings in a room fire situation the data are directly applicable to products that have a formal classification. This is an important feature of the present work as the developed method relies on input data that is widely available.

# 1.4 The methodology

Using the characteristic fire growth from a product as additional input when creating a design fire implies that the process shown in Figure 1 is modified as shown in Figure 2.
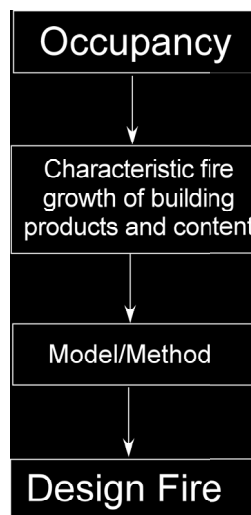


**Figure 2**    **The methodology to create a design fire by using characteristic fire growth of products.**

*The occupancy* is defined in the same way as for the default method, Figure 1.

*The characteristic fire growth of the building products and building contents* can be found using four different approaches.

1.  Taking the actual HRR history of the product in question.
2.  Taking an average HRR history for a product category[1].
3.  Selecting the HRR history based on generic data.
4.  A default HRR curve based on occupancy.

Option 1 is to use the product data for the object in question. That is to take the actual HRR curve for the room lining, the actual HRR curve for the upholstered furniture and so on. This approach gives the highest accuracy, as we then know directly how the involved products will burn. However, buildings are redecorated, furniture items are changed etc. Therefore option 1 is only practical when there is full control of the construction materials and the content. This might be the case for trains, buses and other special enclosures.

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[1] The concept is easily extended to allow for differentiation of a product category into a 'worst case scenario', a 'wood-material based scenario' etc, by suitable selection of averaging data.

Option 2 is to define an average HRR curve for a whole group of products, e.g. the average HRR curve in the Cone Calorimeter for Euroclass B or Nordic class I products. This is useful as it relies on information that is widely available. All building products covered by the construction products directive will be declared with a Euroclass. For upholstered furniture the characteristic fire growth can be identified for large product groups e.g. domestic furniture using research from the CBUF project [11]. Option 2 relies on generalised data and should therefore be widely useful.

Option 3 is to identify a characteristic HRR curve based on generic data. This is rather simple for some products, e.g. wood that has a very characteristic burning behaviour. For upholstered furniture it is known that some fabric (e.g. wool) and foams (e.g. CMHR[2] foam) have characteristic burning behaviour. Option 3 is feasible to use when traditional materials are used in construction and for the building contents.

Option 4 is the default option. Based on the occupancy only, a design curve is directly selected, i.e. the procedure shown in Figure 1. This option is very simple, but on the other hand so crude that it is questionable.

For all the options, uncertainties can be defined by using statistics. However, data to accomplish such estimates are very scarce.

# 1.5     The model/method

The model or the method used to create the design fire can be very simple. However, it requires that the influence of the room/space where the fire takes place be considered. This is especially true for the linings. It also requires that the interaction between the building contents, furniture etc is accounted for. This can be done by simple methods using model room sizes and simply adding the effect from the furniture, see [29].

Another alternative is to use a computer fire model. Some models can accept data from the Cone Calorimeter on linings as well as furniture HRR, e.g. BRANZfire and Conetools. Thus the room scenario in question is input as well as the relevant HRR curves. By using option 2 or 3 for the characteristic fire growth, this also becomes a simple and quick procedure that can be done on any laptop.

For very complicated spaces the zone model becomes uncertain. This can be handled by using a CFD model. CFD is complicated, requires powerful computers, time and qualified staff. Therefore this case is useful mainly for large projects.
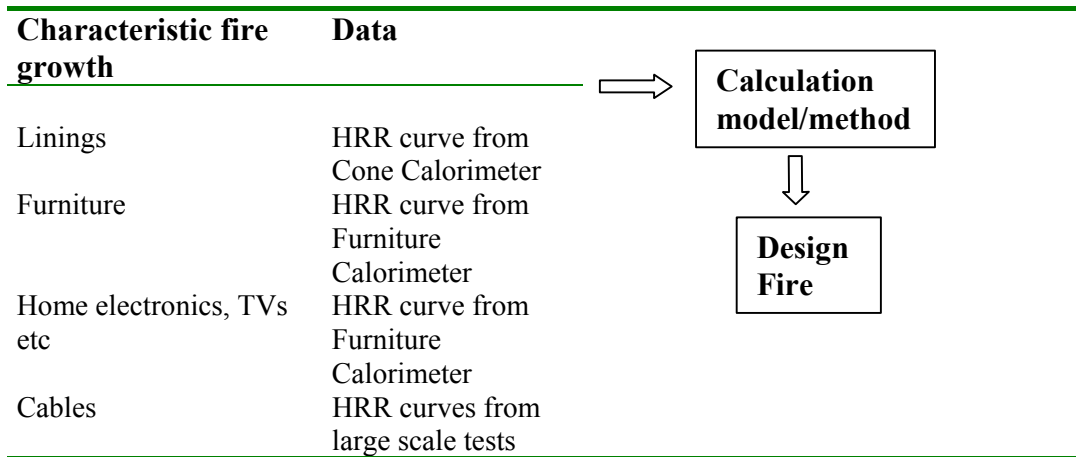
# 1.6     The design fire

The methodology described above can be applied at different levels of complexity. It can be very simple, not requiring specialised staff and quick to apply. It can also be a sophisticated project. In either case the accuracy of the resulting design fire is expected to be considerably larger if one avoids the default method.

In the remainder of the report we will concentrate on further developing the method for linings, cables and the building content according to the principle given in Figure 3.

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[2] Combustion Modified High Resilence Foam

| Characteristic fire growth | Data | |
|---|---|---|
| Linings | HRR curve from Cone Calorimeter | |
| Furniture | HRR curve from Furniture Calorimeter | |
| Home electronics, TVs etc | HRR curve from Furniture Calorimeter | |
| Cables | HRR curves from large scale tests | |

Calculation model/method

Design Fire

**Figure 3    Principles in developing the design fire.**

# 2 Computer models for prediction of fire growth

The flashover phenomenon is the key element in the particular danger of an enclosure fire. This is the point in the fire development where the fire heat release rate increases rapidly and the combustible gases that are transported to the outside of the enclosure through vent openings are sufficiently hot to foster the spread of fire from the room of origin to adjacent spaces. Even before the flashover, the conditions in the room where the initial fire is evolving will be life threatening. In an ideal case, a design fire would have provided a means for the architect to design the room in such a way that enough time would have been given for people to leave the room unharmed.

There is a principal difference between an enclosure fire where furniture can be considered as the sole cause of heat release and cases where combustible surface linings must be included in the calculation. The furniture, even though occupying a certain volumetric space, can be considered as a point source in the fire model and the fire evolution depends only on this point source and the degree of ventilation in the room.

In a fire where combustion of surface linings are involved, the fire dynamics are related to the particular geometry of the enclosure as well as to the lining material. Usually the material will also be different at different surfaces, producing various fire evolution characteristics, depending on the surface. Also the location of the 'point source' in this environment will have to be taken into consideration since it will be important for the ignition of surfaces. A tool for creating design fires in enclosures will therefore have to be able to include both geometry and ventilation of an enclosure together with the characteristic features of surface materials, as well as fire characteristics of possible local point source fires.

There exist basically two methods for doing more advanced enclosure fire simulations: Field and zone models. The first method is based on first principles and uses time and space dependent partial differential equations to describe conservation of mass, energy and momentum in a fire scenario. This is done using some CFD-based (**C**omputational **F**luid **D**ynamics) tool, such as FLUENT, CFX or SOFIE.

The zone model makes the assumption that an enclosure can be divided into two well-mixed zones where each one is described by an average of the qualities in that volume[3]. The method decouples space dependency from the equations, (partly due to the fact that the boundary between the zones is considered as moving), which means that the time dependent system can be described by ordinary differential equations. This is an important simplification and the assumption of having two well-mixed volumes is often quite accurate for enclosure fires, at least when the volume is 'small enough' in relation to the fire.

The field model has the advantage of being more general and there is an expectation within the fire community that fire simulations based on field models soon will become an efficient tool for fire simulations. There are, however, several peculiarities of the physical phenomena of a fire that make simulations intrinsically difficult, in spite of faster computers and increased resolution of the computational space. These difficulties are summarised by the word 'non-linearity', a quality of the fire-system that reveals itself through turbulence and other instabilities, such as the flashover phenomenon. Even if the

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[3] Basically a one-zone model could also be used but this further simplification is for the normal case, only appropriate if a post-flashover situation is modelled.

field model might be able to capture the fire behaviour more correctly, it requires a great deal of computational time and operator skills to succeed with such a simulation.

An alternative is to use a simpler model such as a zone model. This does not mean that such a simulation can be performed without 'skills'; on the contrary zone modelling requires a thorough understanding of the physics involved, in order to be able to judge if the outcome can be considered realistic, although, the numerical and computational skills necessary for the CFD-based approach are not required.

Another topic that one must be able to include in the model is the burning characteristics of the surface material in the enclosure. Such information is available from different fire tests and is, for instance, obtained with relative ease from small scale Cone Calorimeter tests [12]. One source for information on surface material quality is the Euroclass system for reaction to fire performance of surface lining materials, where the material is classified according to its behaviour in the SBI (**S**ingle **B**urning **I**tem) [13] test.

In this report, two different tools that incorporate Cone Calorimeter test results of wall and ceiling linings for simulating the ISO 9705 [14] Room-Corner scenario will be compared and the results evaluated against experimental data. Also, some simulations on larger spaces will be compared to experiments where different point fire sources. The utility of such tools for creating design fires will be discussed and a comparison between the models shown when using averaged Cone Calorimeter data, based on different Euroclasses.

Two different models were used for the investigation. One is a zone model, BRANZfire, developed mainly at the **B**uilding **R**esearch **A**ssociation of **N**ew **Z**ealand [15,16]. The simulation tool BRANZfire[4] can be used on all enclosure sizes, including a multitude of rooms and the initial fire can be defined freely by an appropriate set of HRR-data. The other model, Conetools, is an area-based semi-empirical model developed at SP, Sweden [17]. This model is specifically designed to transfer data from the Cone Calorimeter to an ISO 9705 Room-Corner or an SBI scenario.

There are many zone models available and perhaps the most well known is CFAST [18], developed by NIST (National Institute of Standards and Technology), USA[5]. All zone models (more or less) use the same set of equations for describing the evolution of fires in enclosures. BRANZfire, however, adds the possibility of simulating flame spread on all surfaces in the enclosure, apart from the floor. An option for including a floor model is, however, being developed and is planned to be part of future versions of BRANZfire [19].

It is clear that the basic assumption underlying the zone model used in BRANZfire, which says that the enclosure space can be divided into two separate volumes, one upper and one lower, where each can be regarded as a 'well-stirred reactor' (i.e. that complete mixing is achieved) is at risk when the enclosure space becomes large. However, exactly where the size limit lies is difficult to say and it depends not only on the total volume enclosed, but also on the intensity of the fire and on the degree of ventilation in the enclosure.

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[4] It should be noted that BRANZfire is continuously being developed and improved and that most simulations presented in this report are based on the 2001-2 and 2001-3 versions.
[5] http://fast.nist.gov/

# 3     The data sets

In order to test and validate the models, several sets of experimental data were needed, including both Cone Calorimeter data and measurements from full-scale experiments. Since the Conetools model is limited to simulating the transformation Cone Calorimeter experiment→ISO 9705 Room Corner or the EN 13823 SBI scenario, it was necessary to obtain data for these particular experimental set-ups.

The data most easily available for this project were those from previous research activities where SP has been involved, such as data from the EUREFIC project [20, 21, 22] and the SBI Research Program [23]. In both these cases, data from the Cone Calorimeter as well as data from full-scale experiments in the room corner scenario were available. From the EUREFIC program data was also available from experiments performed in an even larger scale [21] than the room corner scenario. This data was compared to simulations performed in BRANZfire.

Another set of experimental data in larger rooms was obtained from experiments made in relation to a video recording made for educational purposes on the early stages of a fire and the role of surface lining in the development of a fire [24].

# 4 The experiments

Experiments were performed in an ISO 9705, Room Corner scenario. The room is a 2,4x3,6x2,4≈21 m$^3$ (length·width·height) enclosure with a 0,8x2=1,6 m$^2$ (width·height) door opening.

When the particular ISO 9705 [14] test scenario is used, the ignition source is a propane-based square sand burner, located in a corner of the room. The burner effect is initially 100 kW but after 10 minutes it is increased to 300 kW. This is the experimental set-up that can be simulated by the Cone-tools model [17]. The ISO 9705 Room-Corner scenario is often used as a reference set-up for enclosure fires and for classification of different products and/or materials with regards to fire behaviour.

Another, larger space, where experimental measurements were taken in the EUREFIC project, was a 6,75x9x4,9≈298 m$^3$ enclosure [21] with a 2x2=4 m$^2$ door opening. The same types of surface materials were used as for the smaller Room-Corner scenario. Due to the larger size, an increased burner effect was tested. The propane-based square sand burner started by the same cycle, i.e. 100→300 kW after 10 minutes but after another 10 minutes the propane flow was increased so that a total HRR of 900 kW was achieved. Tthe diffusion burner was still placed in the corner.

In a third set of experiments, a 4x5x2,4=48 m$^3$ space with a 2,25x0,7≈1.6 m$^2$ door opening was used [24]. The measurements were made for a video recording ('600 °C') made for educational purposes. In one of the experimental set-ups, an armchair was ignited and used as the 'point source' of the enclosure fire. Data was collected for two different cases: One where Euroclass B materials surface linings were used (plaster board) and one where the walls (apart from the wall through which video recording was performed) were covered with a high-density particleboard and the ceiling with a hard-board material. Both of these surface materials belong to the Euroclass D with regards to reaction to fire, according to the European standard EN 13501-1 [25]. In another experimental set-up, a 30 kW propane based diffusion burner[6] was used as the point source instead of the armchair, and the experiments with different Euroclass surface linings were repeated.

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[6] For 'diffusion burner' see for instance [14].

# 5 The results

Information on surface linings from tests made in the Cone Calorimeter, according to the international standard ISO 5660-1 [12] and test data basically from the Furniture Calorimeter on furniture items was used as input for the simulations. Conetools [17] and BRANZfire [15,16] were used for the actual modelling.

The intention of this work is not to discuss the different simulation tools used; they were used as examples on how to implement the suggested method. However, it is necessary to give some information with regards to the models since one has to understand why the method sometimes fails and sometimes is a success and how the method could be improved.

Cone Calorimeter data was used for simulating 29 different real scale experiments. The results are shown in appendix A. There are no (to our knowledge) accepted scientific criteria as to what signifies a 'good' or 'bad' coherence between a simulation and experimental results. Looking at the figures it is evident though that in some cases the simulation has failed to predict the experimental result but also that the accuracy frequently is 'quite' good.

Some of the simulations that do not show good agreement with data can be explained by variations in combustion behavior depending on whether the material is positioned horizontally, as in the Cone Calorimeter or vertically, as in a real scale test. Also, the Cone Calorimeter might not give applicable values for other reasons; i.e. the irradiance level used might have been too low during the test, e.g. if the tested material was covered with some non-combustible surface coating that would have needed a higher irradiance level to 'crack' and allow for ignition. Particular characteristics of this kind will be discussed in more detail in the sections describing the tested groups of materials below.

Some 37 of the tested materials were used in the ISO 9705 Room Corner scenario and the results are shown in figures 20-57 (appendix A). Not all necessary Cone Calorimeter data were available for the BRANZfire simulations (that requires data from at least three levels of irradiation in the calorimeter) which is why the number of simulations differ for the two modelling tools.

One qualitative indicator of the simulations could be the capacity to predict flashover/non-flashover. These results are summarised in table 3. The simulated result is given followed by the experimental result within paretheses followed by the 'procentage correctness'. It is seen that Cone tools obtains a somewhat higher score but one should remember that this software is particularly designed to make the transformation Cone Calorimeter-> Room-Corner (or SBI) whereas the software BRANZfire is more general.

**Table 3    Comparison between simulated and experimental predictions.**

|  | BRANZfire | Cone tools |
|---|---|---|
| No flashover | 5 (6)=83% | 13 (15)=87% |
| Flashover | 12 (15)=80% | 19 (23)=83% |

One should also note that within the experimental series there are materials that are not well represented by their Cone Calorimeter behaviour, as mentioned above. In one case were the experiment exhibited flashover, both simulation tools failed to predict correctly (fig. 44) and for another case the tools predicted a flashover but this was not found in the experiments (fig. 36). Apart from making these materials unsuitable for the proposed modelling, it also indicates that these two materials may have characteristics that make them unsuitable also for the ISO 5660 Cone Calorimeter test.

Generally, Conetools calculates the time to ignition of the surface lining as if the material is 'thermally thick'. The input data used in this project are based on a 50 kW/m$^2$ irradiance level in the Cone Calorimeter but Conetools is originally optimised for HRR data from a 25 kW/m$^2$ level. Therefore the ignition time had to be adjusted and it was decided that thermally thick behaviour was to be expected for most cases. For thermally thick materials [26] the time to ignition scales as[7]

$$t_{ign2} = t_{ign1}\left(\frac{q_1}{q_2}\right)^2$$

but for 'thermally thin' materials, the ignition time scales as

$$t_{ign2} = t_{ign1}\left(\frac{q_1}{q_2}\right)$$

There is evidently a field of intermediates between the two cases.

If the material used was to be considered 'thermally thin' rather than 'thermally thick', the Conetools simulation would be likely to overestimate the HRR production. Similarly, BRANZfire sometimes seems to have problems simulating thermally thin materials correctly.

## 5.1　　　EUREFIC Room Corner

The EUREFIC research programme [20] was initiated in the late 1980'ies as a Nordic initiative to improve the technology of fire testing of wall and ceiling materials. Heavily influenced by the results of this programme, the international standards ISO 9705 [14] ('Room-Corner') and ISO 5660 [12] ('Cone Calorimeter') were developed and accepted as means for testing of surface lining materials.

In the text to the final report it is suggested that Cone Calorimeter data should be used as a tool for predicting full-scale behaviour and the software 'Conetools' was developed for this purpose. In the report is also mentioned the use of HRR information from the Cone Calorimeter for simulating fire spread in a field model ('KAMELEON').

EUREFIC experiments and simulations are shown in appendix A. All figures shows the Room Corner, ISO 9705 fire scenario.

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[7] see section 6 below

## 5.2 The SBI research program

The SBI research program [23] was performed in order to develop an intermediate scale test, the SBI-test [13], of surface linings and the aim was to use this test as a major procedure for classification according to the forthcoming Euroclasses. The program was led by the European Commission-DG enterprise, in cooperation with a group of European regulators, the Fire Regulators Group (FRG). Different European fire laboratories were involved in the development, including SP.

In the program, 30 different building products were tested in the Room-Corner scenario, according to ISO 9705. Comparisons between these experiments and simulations using BRANZfire and Conetools are shown in appendix A.

For this group of materials it is seen that Conetools responds somewhat too quickly. In two cases the material used might be considered as less suitable for the proposed method:

- FR polycarbonate panel 3 (figure 36)
- Intumescent coat on particleboard (figure 44)

Both materials will behave differently depending on positioning. The first material will melt and flow downwards towards the floor during the fire when positioned vertically and the second material is covered with a protective coat that will fall off during a fire when positioned vertically.

## 5.3 EUREFIC Large Scale

Several experiments were also performed within the EUREFIC project in a 6,75x9x4,9 m$^3$ enclosure [21] with a 2x2 m$^2$ door opening. The theoretical heat release in such an enclosure for reaching a flashover situation can be estimated to be approximately 4 MW [27].

Only the zone model BRANZfire was used for this simulation. Of the 4 cases tested, one experiment went to flashover (fig. 58) and the model did manage to simulate this, even though the time to flashover was somewhat shorter in the model compared to reality.

## 5.4 600 °C

In the video recording made for educational and demonstrational purposes where the impact of using different surface linings was demonstrated, detailed measurements of temperatures and rate of heat release were also made. These data could then be compared to a simulation using the Zone model. The experiment intended to show the pre-flashover fire development.

The enclosure was a 4x5x2,4 m$^3$ space with a 2,25x0,7 m$^2$ door opening, which indicates a theoretical HRR of ~1.5 MW to reach flashover.

The enclosure was a simple cubic volume, furnished like a hospital waiting room. Three of the walls were covered with either wood type (Euroclass D) or plasterboard (Euroclass B) linings. Also the ceiling and the floor were covered with suitable materials. The fourth wall was made partly of glass in order to allow observation and filming of the events. Even though the glass wall changes the thermal characteristics of the enclosure compared to if the walls were all of the same material (which is assumed in the two models used),

the impact can be considered as minor since flame spread to this wall could only occur as a result of a flashover or close to flashover situation.

In a first experiment, an armchair was positioned in one of the corners in a room where linings of Euroclass B were used. The resulting HRR-curve, shown in figure 63 (appendix A), was used as the point source fire in the zone model. Figure 64 shows the measured temperatures at different heights, together with the simulated temperatures for the 'upper' and 'lower' layer respectively. In figure 65, the height of the simulated neutral plane separating the two layers, is shown. As can be seen from the measured temperature gradient in the room (figure 64), the calculated layer seems to be positioned correctly.

For the next experiment, surface linings of Euroclass D were used. Figure 66 shows the measured and the simulated HRR for this experiment. As can be seen the result of calculating the flame spread contribution to the HRR is quite accurate and the time to reach flashover (~1500 kW) is virtually the same in the simulation as the measured value.

Figure 67 and 68 shows the measured/calculated temperatures and neutral plane respectively. The calculated upper layer temperature is perhaps a bit high. The same applies for the neutral layer and it seems logical that a too high position of the neutral layer accompanies a too high upper layer temperature (when the HRR-evolution is simulated correctly), simply because a smaller gas volume containing the same amount of energy as a larger one, must have a higher temperature.

Figure 69 shows a comparison between the simulated and measured evolution when the ignition source is a 30 kW diffusion burner. As can be seen the model does capture the flashover phenomenon but a bit too late compared to the experimental result.

# 6      Euroclass based design fires

It should be stated that any attempt to use a general model for creating a design fire based on a rough estimate of the fire characteristics of a material, is liable to induce large error in the estimates. The reason is the particular difficulties that are related to non-linear phenomena in the evolution of a fire. The non-linear behavior, where an 'infinitely small' variation of the initial data in a fire scenario can result in very different end results, reveals itself most clearly through turbulence or other instabilities, such as flashover.

However, it is also true that different materials can be typified according to their behavior and that this behavior can be measured according to some general rules, such as the Euroclass system for surface materials [13].

Indeed, the fundamental idea behind using different standardized fire test methods for classifying materials and to categorize them according to a set of rules such as the Euroclass system is that it *is* possible to define a general behavior for various materials.

The difficulty in creating a design fire then lies in trying to extract the particularities of a set of materials belonging to a certain group. Also, to do this in such a way that the essence of the set is captured in a form suitable for a mathematical treatment, in order to create the design fire.

Figures 4-7 shows HRR-curves for Cone Calorimeter tests of materials belonging to different Euro classes: A2, B, C, D, E and F, where A2 is the best and F the worst case. All curves are based on a 50 kW/m$^2$ irradiance level in the Cone Calorimeter.

Even though there are variations within each group, it seems clear that there is a qualitative difference between the groups. The idea is therefore to try to extract the group qualities from these curves, e.g. by averaging the data.

When looking at the set of curves in figures 4-7 it also seems clear that some of the elements of the set represent what is known in statistics as 'outliers', i.e. they represent some kind of extreme behaviour in the group. Including such an element in the averaging can lead to very strange results, at least when the number of elements is low.

Also, one should bear in mind that the Cone Calorimeter test differs from the tests used for the classification system and that the HRR-behaviour in the cone does not necessarily mirror the real test identically. One particular difference between the tests that could have a major impact is the fact that the test material in the Cone Calorimeter is positioned *horizontally*, whereas the Euroclass system is based on *vertically* positioned material. This means that materials that are influenced by forces of gravity, e.g. through melting or disrupting of the material, can behave differently depending on positioning in the specific test. It might therefore be appropriate to try and exclude some curves from the set before doing the averaging.

 When the number of elements is large, there are mathematical techniques that can be used for the exclusion but when the number is small, as in this case, a more heuristic approach is needed and some of the curves have been excluded by simple visual inspection of the data. The elements excluded are marked in the diagrams. The exclusions can obviously be discussed but hopefully, as the set of Cone Calorimeter data grows, the exclusions can be made on a more thorough mathematical basis.

Cone calorimeter data; Euro class A2+B
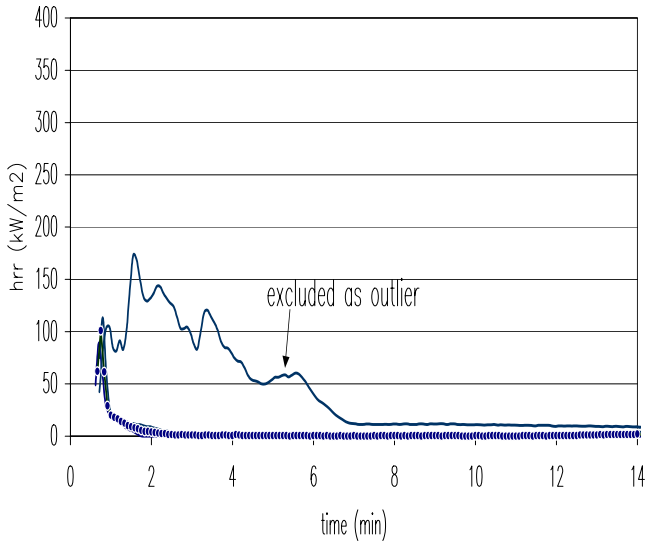


**Figure 4** **Experimental+mean valued Cone Calorimeter data.**

Cone calorimeter data; Euro class C
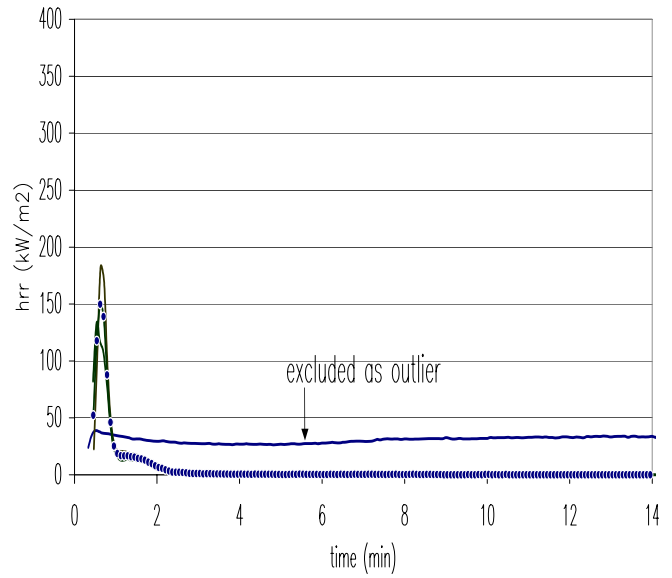


**Figure 5** **Experimental+mean valued Cone Calorimeter data.**

Cone calorimeter data; Euro class D
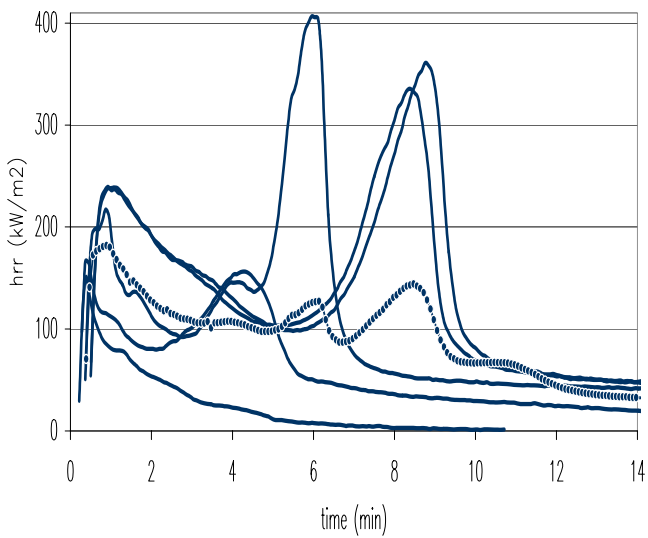


**Figure 6** **Experimental+mean valued Cone Calorimeter data.**

Cone calorimeter data; Euro class E+F
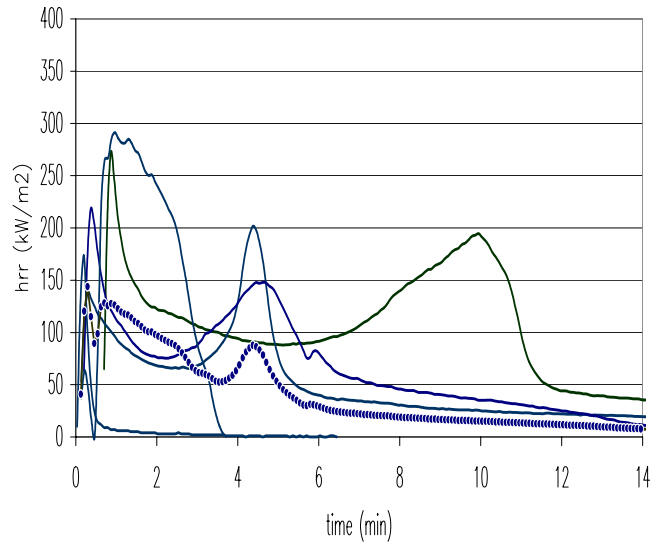


**Figure 7** **Experimental+mean valued Cone Calorimeter data.**

In the diagrams the beginning of each curve is the point of ignition (correctly position in time). The curves marked by lines designate an averaged curve within each class. The averaging was first made for the time to ignition by the expression

$$t_{ign} = \frac{1}{N} \sum_i t_{ign}^i, \quad i = 1..N$$

where 'i' designates a measured HRR-curves. The class-HRR was then averaged by the expression

$$HRR(t + t_{ign}) = \frac{1}{N} \sum_i HRR(t + t_{ign}^i), \quad i = 1..N$$

i.e. the averaged HRR was calculated for the relative time estimate 't+$t_{ign}$' by using the same time lap 't' for all curves, independent on the absolute value of the individual '$t_{ign}$'. The assumption underlying the method was that the important feature of the HRR curve to capture, apart from the time to ignition, is the evolution of the curve once the material has ignited.

A further complication when constructing the data necessary for a design fire by this method is that the models using Cone Calorimeter data frequently need more information than just one measurement. The models used in this investigation, Conetools and BRANZfire, also have particular demands on necessary input data. In Conetools, the model is based on using time to ignition from a Cone calorimeter experiment with an irradiance level of 25 kW/m$^2$. BRANZfire needs Cone calorimeter ignition times for at least two different irradiation levels and also the accompanying maximum HRR values. The Cone calorimeter data available do not necessarily meet the different demands and it is therefore useful to have acceptable methods for transforming the available data to the requested format.

All curves in figures 4-7 represent results from the Cone Calorimeter at a 50 kW/m$^2$ irradiance level. If the time to ignition is known at one level of irradiance, the ignition time at another level can be estimated by the following general procedure:

Assuming that the material to be tested in the Cone Calorimeter can be regarded as a one dimensional, semi-infinite solid, the equation, with suitable boundary (x=0) and initial (t=0) condition describing the temperature evolution when irradiance at a level $q_1$ is applied, can be written

$$\frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2}, \qquad \frac{\partial T(t,0)}{\partial x} = -\beta q_1, \quad T(0,x) = T_0$$

In this equation 'k' represents (constant) material characteristics and 'β' is the coefficient of heat transfer. This linear partial differential equation has an analytical solution that can be written

$$T(t) = T_0 + \alpha q_1 \sqrt{t} \cdot f(t,x)$$

where $\alpha$ is a constant that contains among other things, k and $\beta$. The function f(t,x) is is equal to 1 for x=0, i.e. at the surface the following is true

$$T(t) = T_0 + \alpha q_1 \sqrt{t}$$

or, at the time for ignition at the irradiance level $q_1$

$$t_{ign_1} = \frac{(T_{ign} - T_0)^2}{(\alpha q_1)^2}$$

Now, if it is assumed that the surface temperature for ignition, $T_{ign}$, of a material is the same independent of the level of irradiance, the last expression will be repeated for an irradiance level $q_2$ and the ignition time for this level can be calculated from the simple expression

$$t_{ign_2} = t_{ign_1} \left(\frac{q_1}{q_2}\right)^2 \qquad (1)$$

This information is sufficient together with the averaged HRR data for using Conetools. Many of the materials that are represented by Cone Calorimeter data from the 50 kW/m$^2$ irradiance level in figures 4-7, were also tested at a level of 35 kW/m$^2$. To test the validity of (1), the ignition times at 35 kW/m$^2$ were plotted against values calculated by the equation. The result is shown in figure 8 and it is seen that the correlations are very good. However, the simulations are very sensitive to changes in ignition times, which should be taken into consideration when the results are evaluated.
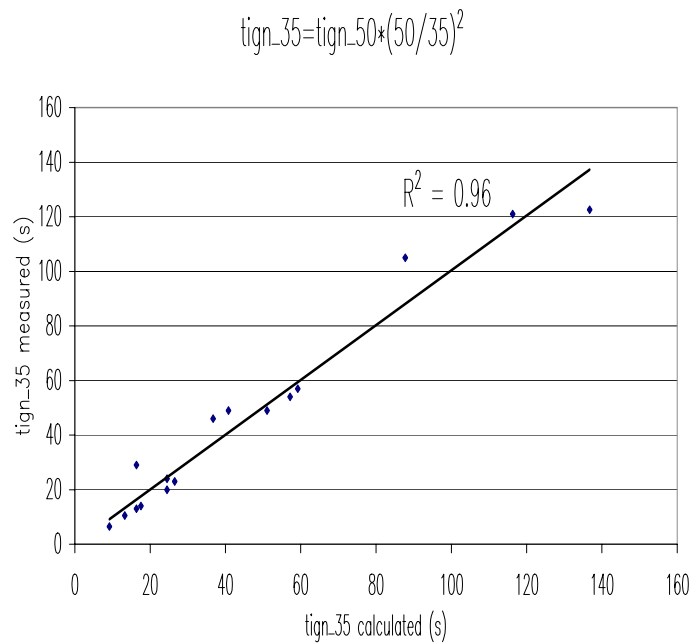


**Figure 8**     **Calculated ignition time vs measured data.**

The model BRANZfire also needs a maximum HRR for the level where $t_{ign}$ was calculated.

Quintiere [28] suggest the following expression for calculating peak HRR values ($Q$) for a burning surface under flux conditions:

$$Q = k(q_f - \sigma T_{ig}^4 + \sigma T^4)$$

where $k$ is a material constant, $q_f$ represents the incident heat flux, $\sigma T_{ig}^4$ is the re-radiation flux loss and $\sigma T^4$ the incident heat flux from the 'room'. The latter should not be important in the Cone Calorimeter context and therefore, the relation between two HRR-maxima as a function of different levels of irradiation ($q_f$) could be written

$$\frac{Q_2}{Q_1} \approx \frac{q_{2f} - \sigma T_{ig}^4}{q_{1f} - \sigma T_{ig}^4}$$

which suggests a near linear relation between the peak HRR values ('$Q_i$') and the level of irradiation ('$q_{if}$'). It also suggests that the higher the temperature to ignition is, the larger the energy loss and the smaller the difference in peak HRR will be for various irradiance levels. If $q_{2f} < q_{1f}$ it also suggests that $Q_2/Q_1 < q_{2f}/q_{1f}$, i.e. that the peak HRR at an unknown level '2' can be assumed to follow the relation $q_{2f} > q_{1f}*(Q_2/Q_1)$.

Looking at different available materials at the 35 and 50 kW/m$^2$ levels (i.e. $Q_2/Q_1=0,7$), it was seen that most data scaled the peak HRR ($q_{2f}/q_{1f}$) in the range 0,72-0,82. A mean value of 0,77 was therefore used to scale the 50 kW/m$^2$ irradiance level, peak HRR values for the averaged Cone Calorimeter data, to a number at the 35 kW/m$^2$ level. The simulations are normally not as sensitive to changing this value as changing the calculated $t_{ign}$.

With the estimated HRR-max and the calculated $t_{ign}$ for the 35 kW/m$^2$ level, it was possible to perform a BRANZfire simulation using averaged data from the graphs shown in figures 4-7. Figures 9-12 shows the result of using these 'typified' Cone Calorimeter data for each class, when simulating the ISO 9705 room corner scenario with Cone tools and with BRANZfire. In the figures the full-scale experimental results for the different materials that were used for obtaining the averaged Cone Calorimeter curve is also shown. As can be seen from the figures the average file predicts a typical behaviour for a material belonging to the group well.

Euroclass A2+B materials in Room corner scenario and
simulations based on averaged Cone calorimeter data
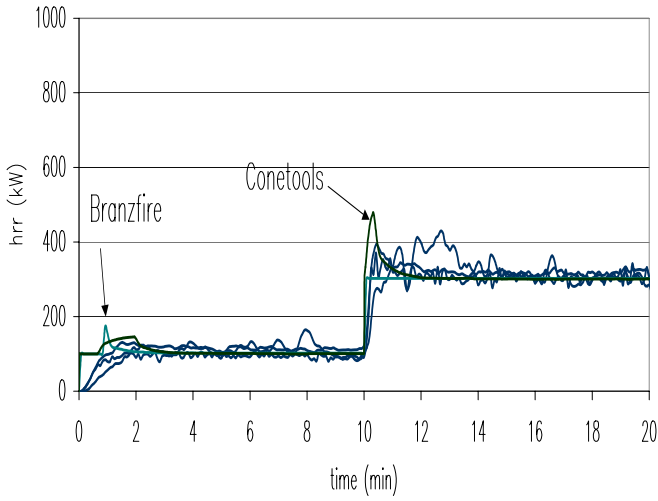


**Figure 9    ISO 9705 data and simulations.**

Euroclass C materials in Room corner scenario and
simulations based on averaged Cone calorimeter data
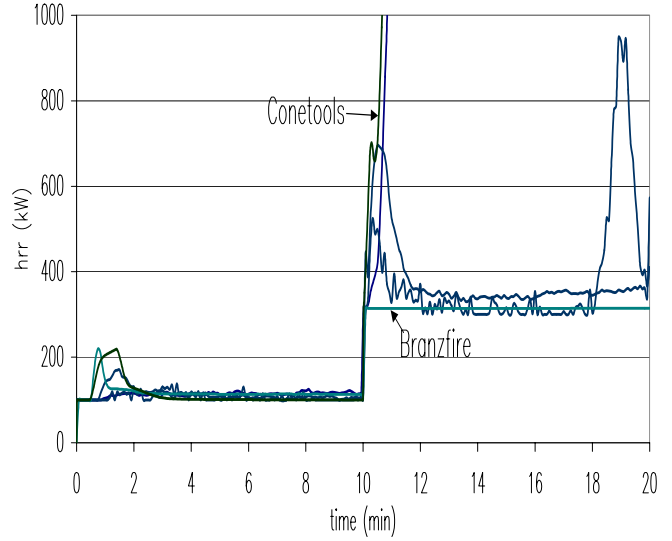


**Figure 10    ISO 9705 data and simulations.**

Euroclass D materials in Room corner scenario and
simulations based on averaged Cone calorimeter data
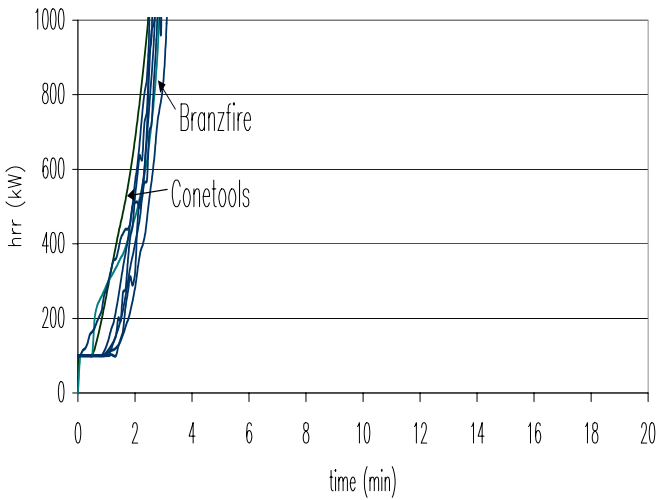


**Figure 11    ISO 9705 data and simulations.**

Euroclass E+F materials in Room corner scenario and
simulations based on averaged Cone calorimeter data
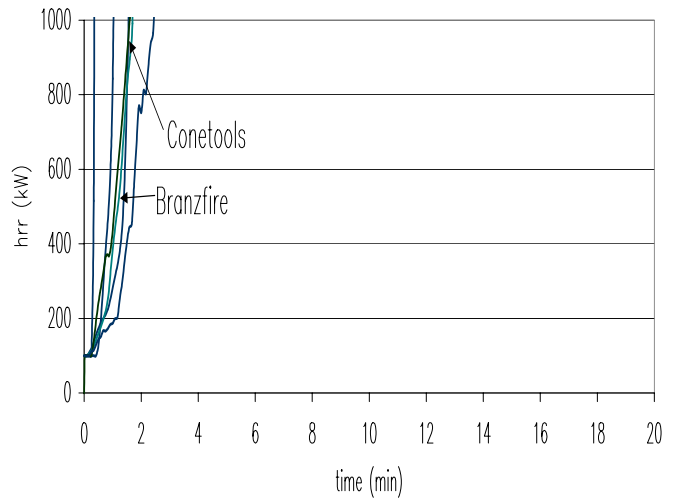


**Figure 12    ISO 9705 data and simulations.**

It is known that as a rule of thumb, a Euroclass A2 or B should not provoke a flashover when used in the ISO 9705 Room Corner scenario. Similarly a class C material *might* induce a flashover after 10 minutes, when the input energy level is increased from 100 to 300 kW. A class D material should reach a flashover somewhere in between 2 and 10 minutes and Euroclasses E and F should provoke a flashover in a shorter time period than 2 minutes. All these features are well illustrated by the simulations using the averaged Cone Calorimeter curves, with both simulation tools.

# 7 Comparison with previous results

It is of interest to compare the results obtained by the Cone Calorimeter data averaging procedure with other investigations. In a previous study [29] design fires were suggested for different surface lining materials, classified according to a Swedish national standard as class I, II or III. By studying experimental data (EUREFIC-data were used, among other sources), it was found that in a 'small' room[8], a class I material ($\approx$Euroclass B) where an initial ignition source ($Q_0$) having a HRR<100 kW, would not show any flame spread, whereas for $100<Q_0<300$ kW, a Gaussian curve defined by

$$Q = 300\exp\left(-0.6(t-1.7)^2\right) \qquad (2)$$

would be a suitable design fire (t in minutes).

For the class II and III material ($\approx$Euroclass D) and the same type of small enclosure, another design fire would be expressed by a $t^2$-type of fire according to

$$Q = Q_I\left(\frac{t}{t_g}\right) \qquad (3)$$

where $Q_I$ is a constant (1 MW), t is time (in seconds) and $t_g$ is a 'characteristic time', defining a *slow* ($t_g$=600 s), *medium* ($t_g$=300 s), *fast* ($t_g$=150 s) or *ultra fast* fire ($t_g$=75 s).

For class II and III materials, the relations again based the different design fires recommended on the assumed ignition source:

- $Q_0$<40 kW      =>slow fire
- 40 kW<$Q_0$<100 kW    =>medium fire
- 100 kW<$Q_0$<160 kW    =>fast fire
- $Q_0$>160 kW      =>ultra fast fire

In figures 13 and 14 are shown the result from simulating an ISO 9705 Room Corner scenario from mean valued Cone Calorimeter data, together with the design fires made for the slow, medium, fast and ultra fast situations.

The simulations were made using BRANZfire and it is seen that the design fires based on the averaged Cone Calorimeter data for the Euroclass B material represents a subset of the old design fire method. However, for Euroclass D materials it is seen that the old method gives somewhat too low HRR characteristics compared to the new method, except for the 'ultra fast' fire which seems to be conservative enough, at least as long as the ignition source in the Room Corner scenario is not too far above 160 kW.

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[8] floor area< 60 m$^2$, height<5 m
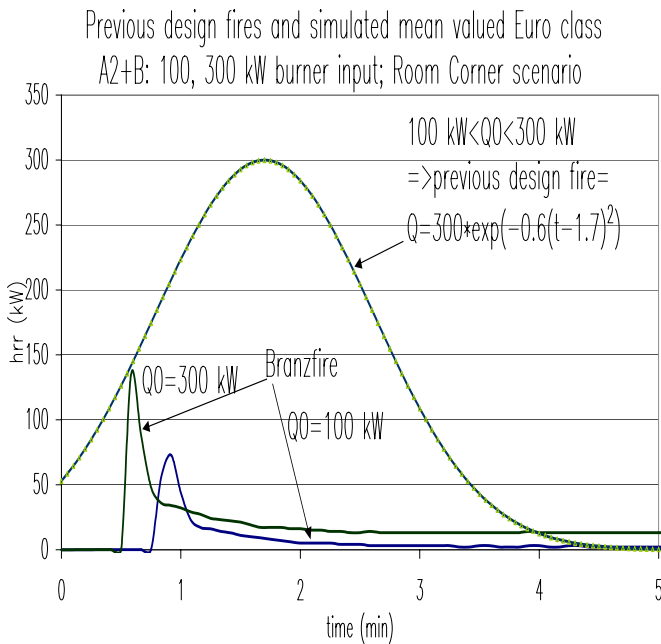
**Figure 13**   **Comparison with previous design fire results.**
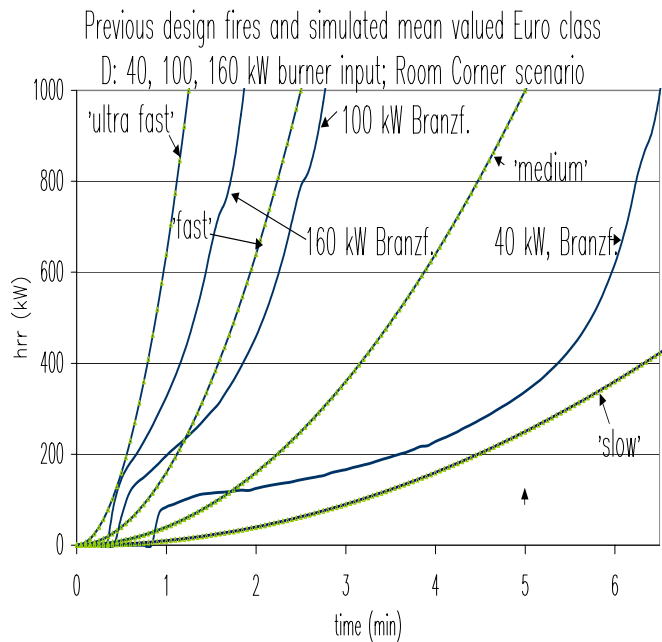


**Figure 14**   **Comparison with previous design fire results.**

Looking at the example for a 'medium' fire, it is known, as stated earlier, that using a Euroclass D material might induce a flashover in the ISO 9705 Room Corner scenario after 2 minutes (worst case). The ISO 9705 test procedure states that initially a 100 kW ignition source should be used. The medium sized design fire should cover any situation in the Room Corner where the ignition source is greater the 40 kW but smaller than 100 kW, i.e. including also 99.99999... kW. This indicates that the 'medium' design fire is not restrictive enough, since the method gives a flashover at more than 5 minutes (see Figure 14). On the other hand the design fire 'fast' should be valid for situations where the ignition source is less than 160 kW but greater than 100 kW, i.e. including also 100.000001. This design fire *will* cover the Euroclass D worst case in the Room Corner scenario but it is clear that very different results are obtained if the initial ignition source is assumed to be 99 or 101 kW. The suggested method based on averaged Cone Calorimeter data will give a more differentiated picture of the events.

# 8       Comparison with SBI data

The basic idea behind the proposed method is that it is possible to use Cone calorimeter data, typified by the Euroclass system for surface lining material, to derive input data for simulating fires in enclosures, clad with different Euroclass materials. Some of the results obtained are shown in figures 16-19.

One way of testing the idea further is to 'close' the proposed system by using the averaged curves for simulating fires in the test called SBI (Single Burning Item [13]) since this test is a cornerstone in the system for defining Euroclasses.

Based on the SBI-test, different surface lining materials are classified according to the Euroclass system. From this classification, the proposed method uses Cone calorimeter data in order to create 'typical' Cone calorimeter data files for each class. From one data file it should be possible to obtain 'typical' SBI results for the class chosen, provided the file is made correctly and provided there are simulation tools available for the task.

The simulation model 'Conetools' used in this report for simulating fires in the ISO 9705 Room Corner scenario, also includes the possibility of simulating the SBI test from Cone calorimeter data [30]. The result from running the averaged Cone calorimeter data in the model is shown in figure 15.
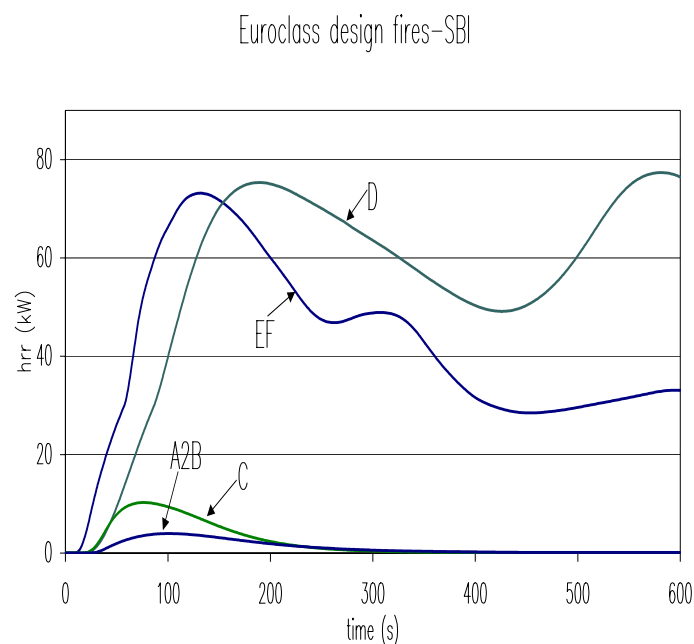


**Figure 15   SBI-simulations based on averaged Cone Calorimeter data.**

As can be seen the simulations clearly show a differentiation that follows the Euroclass system with regards to the HRR evolution (i.e. A2+B is the 'best' and E+F the 'worst' case).

According to the SBI-criteria for the Euroclass system, different classes are defined by a certain critical FIGRA[9] value. These Euroclass FIGRA-values and the values obtained from the simulations shown in figure 15, are represented in the table below.

**Table 4    Comparison between Euroclass FIGRA and simulated results from averaged Cone calorimeter data.**

| Euroclass | A2+B | C | D | E+F |
|---|---|---|---|---|
| **Classification criteria** | $FIGRA \leq 120 Ws^{-1}$ | $FIGRA \leq 250 Ws^{-1}$ | $FIGRA \leq 750 Ws^{-1}$ | $FIGRA \geq 750 Ws^{-1}$ |
| **Simulation** | $FIGRA = 38 Ws^{-1}$ | $FIGRA = 157 Ws^{-1}$ | $FIGRA = 475 Ws^{-1}$ | $FIGRA = 692 Ws^{-1}$ |

As can be seen, the values obtained clearly demonstrate that the simulations based on averaged Cone calorimeter data provide correct FIGRA, except for the E+F Euroclasses where the value obtained is somewhat low but close to the limit. The good agreement between simulation and experimental data is also clearly demonstrated in figures 16-19, where experimental SBI results are compared to simulations for different Euroclasses[10].
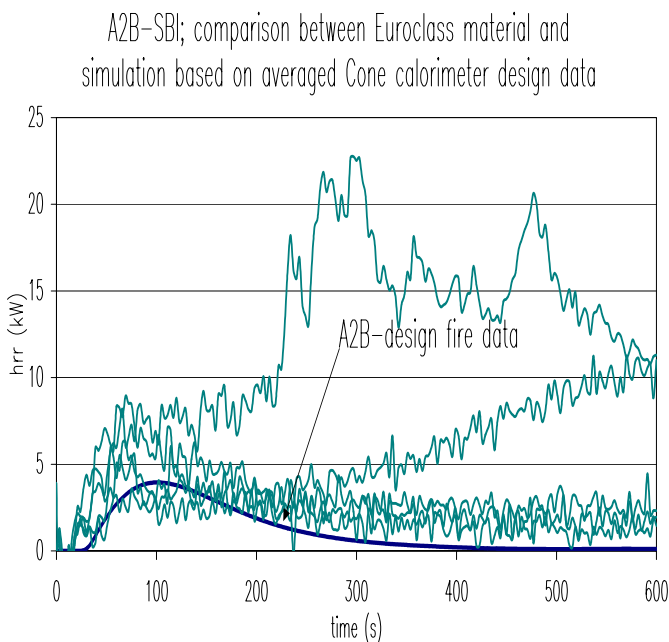


**Figure 16    SBI-data and simulation; Euroclass A2+B material.**
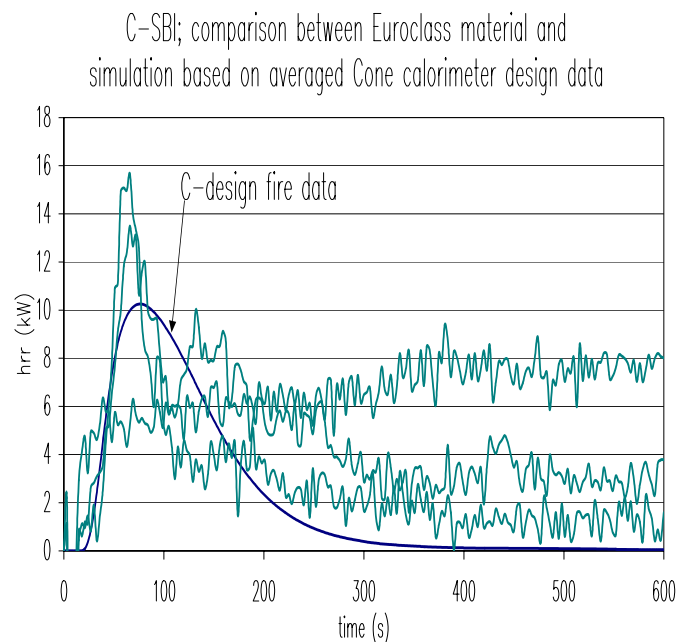


**Figure 17    SBI-data and simulation; Euroclass C material.**

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[9] defined by max_(HRR(t)/t)

[10] Note in figure 50 where there is one material that distinguishes itself compared to the others by providing a much higher HRR after the initial ignition. This is the same material (FR PVC) that was excluded from the Cone calorimeter data averaging procedure, since it was considered an 'outlier' (see figure 38). This shows once again that the small scale Cone calorimeter catches relevant fire characteristics.

D–SBI; comparison between Euroclass material and
simulation based on averaged Cone calorimeter design data

D–design fire data

hrr (kW)

time (s)



EF–SBI; comparison between Euroclass material and
simulation based on averaged Cone calorimeter design data

EF–design fire
data

hrr (kW)

time (s)
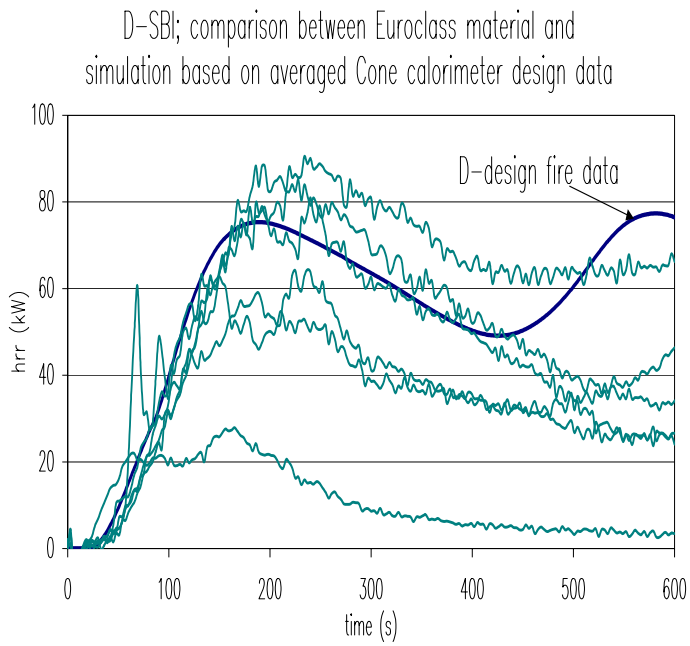
**Figure 18    SBI-data and simulation; Euroclass D material.**
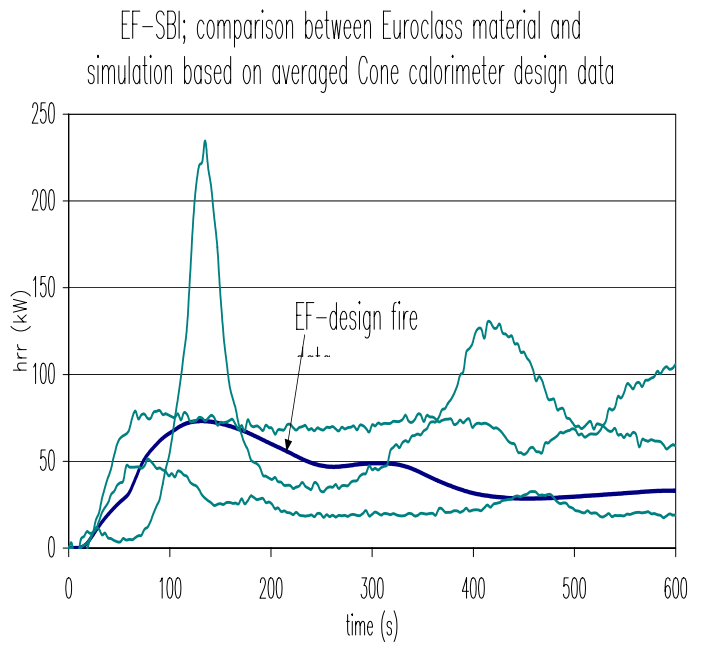
**Figure 19    SBI-data and simulation; Euroclass E+F material.**

# 9 Conclusions

Characteristic fire growth from building products and the building content can be used to create a design fire that is expected to be of substantially better precision than the simplified method of t-square growth that is used today. The fire growth of the building content, e.g. furniture, is combined with the building products, e.g. linings by means of a simple method or by use of a fire model. The methodology can be quick and simple or more sophisticated. The approach demonstrated in this report is based on the use of a zone model (BRANZfire) and a semi-empirical model designed to predict the test results in the Room/Corner (ISO 9705) and the SBI (EN 13823) test.

The characteristic fire growth for linings was taken from the generic information that is given by the Euroclass-classification or the Nordic classes for linings. The average heat release rate curve from the Cone Calorimeter for a specific class was used to characterize the linings.

The creation of the characteristic curve for each class depends on available data and the method is easily extended to allow for further selection criteria as the amount of data is increased. Example of such selection criteria could be Cone Calorimeter data for the Euroclass D material known to provide a flashover within 3 minutes in the ISO 9705 Room Corner scenario or Cone calorimeter data for wood based building material.

The building contents, e.g. upholstered furniture or home electronics are regarded as point sources and therefore the HRR curve used is for the whole item. Again the characteristic fire growth can be defined based on generalized data, i.e. upholstered furniture of office type, domestic, public and so on.

Input from the linings and furniture items were then tried in two models, BRANZfire and Conetools, for room configurations that had been tested in full scale. Experiment compared to predicted fire growth showed good agreement. Flashover/non-flashover was correctly predicted in more than 80% of the full-scale and large-scale experiments.

The work demonstrates that the selected methodology for creating a design fire gives better results than simple t-square assumptions without much extra effort in time and complexity.

In addition data on cables, train products and home electronics is added to support the user of this methodology.

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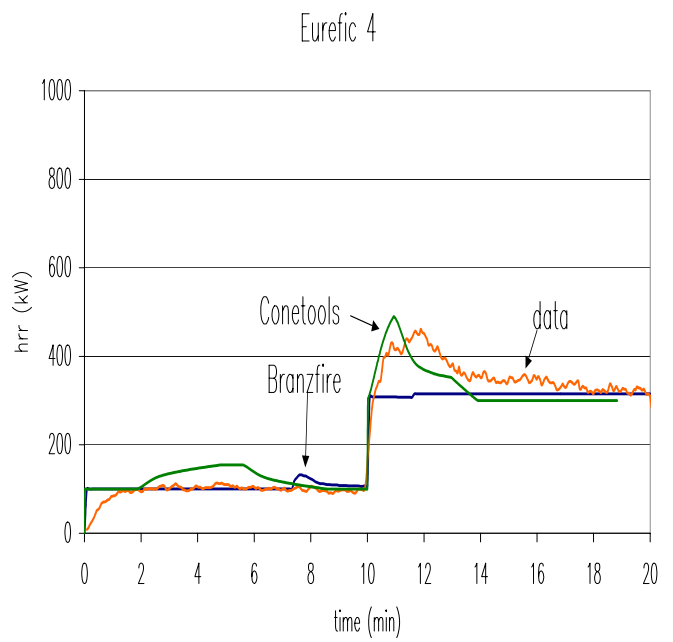
# Annex A    Graph-section

## EUREFIC Room Corner

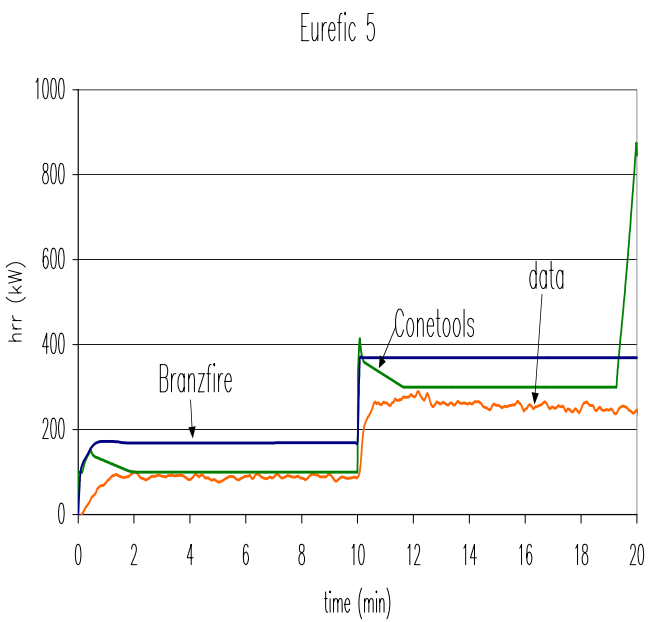Eurefic 1



Eurefic 2
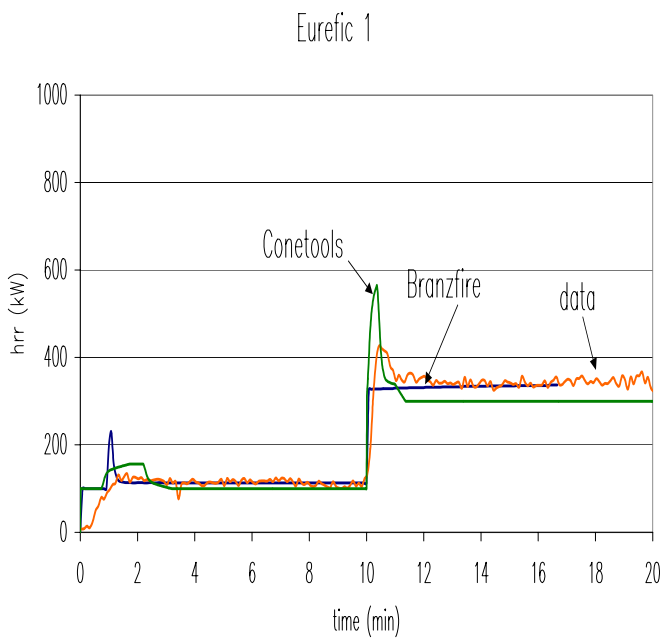


**Figure 20    Painted gypsum plaster board.**
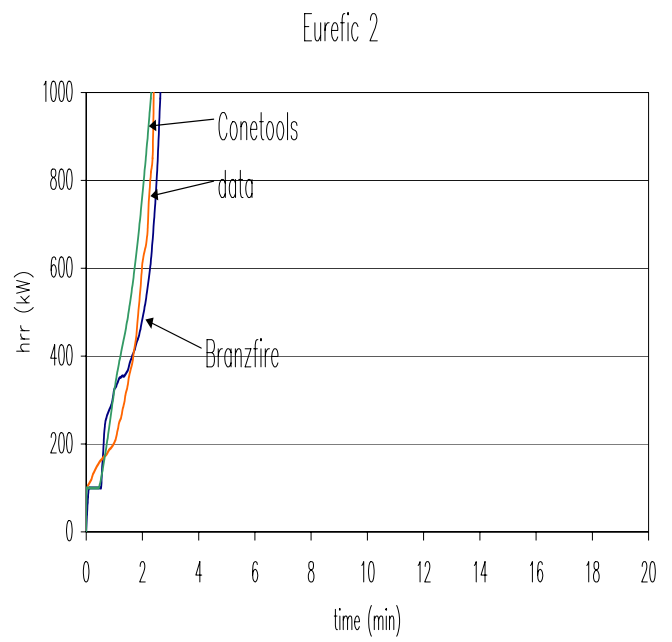
**Figure 21    Ordinary Birch Plywood.**
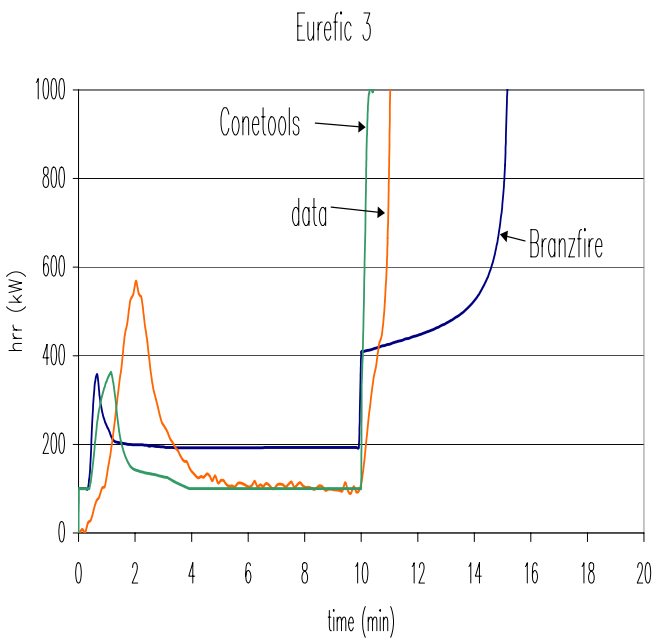
**Figure 22    Textile wall covering on gypsum paper plasterboard.**



**Figure 23    Melamine faced high density non-combustible board.**



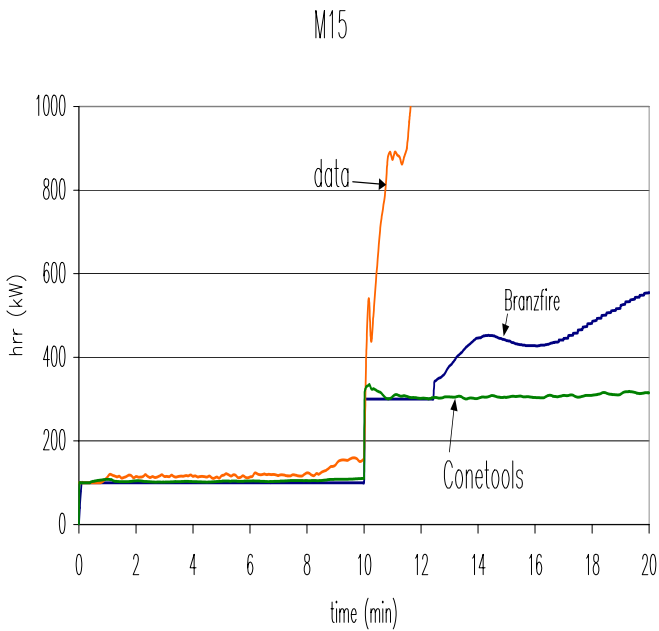**Figure 24    Plastic faced steel sheet on mineral wool.**
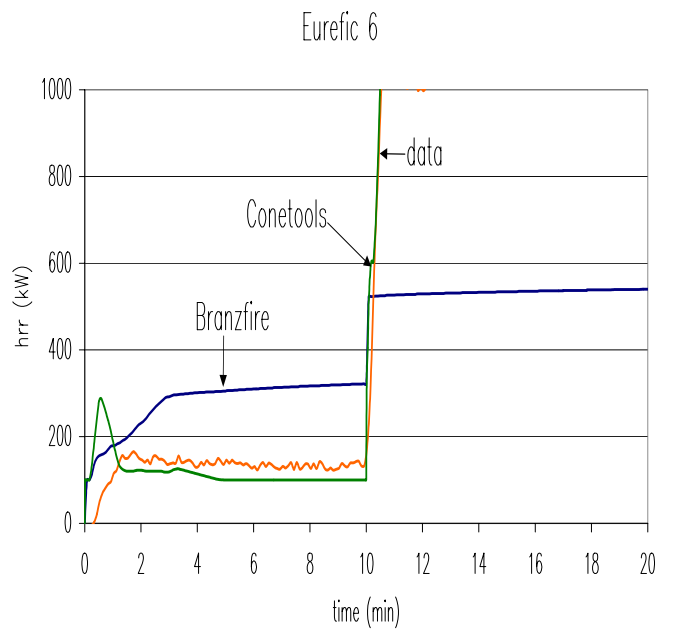


**Figure 25    FR particle board type B1.**
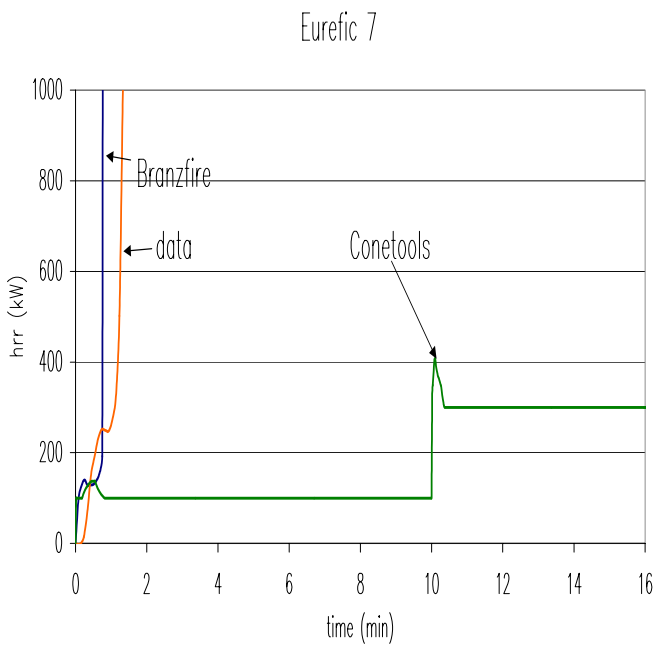
**Figure 26    Combustible faced mineral wool.**
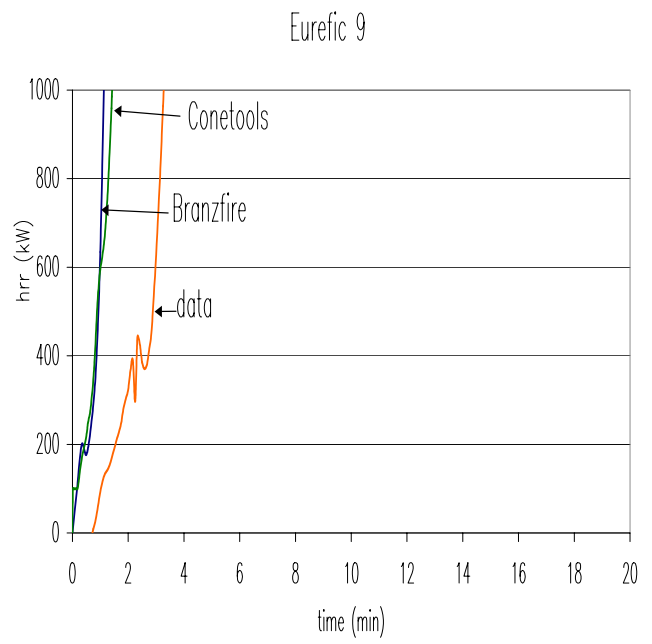


**Figure 27    Polyurethane foam covered with steel sheets.**
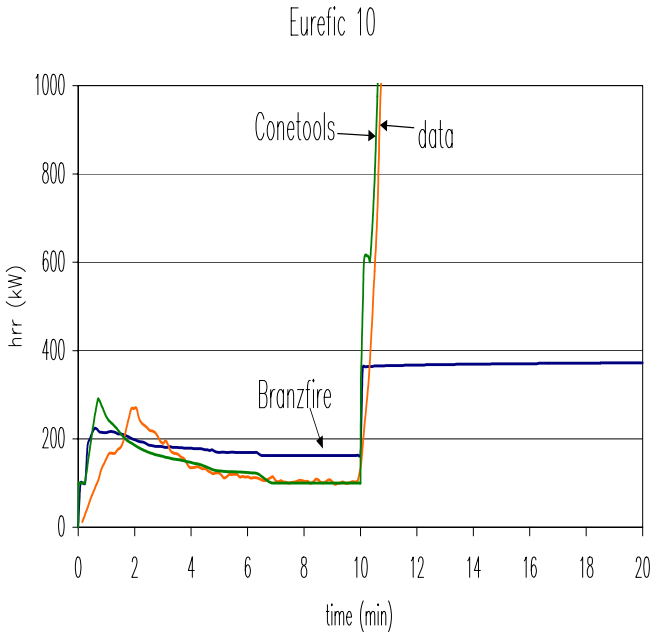


**Figure 28    PVC wall carpet on gypsum plaster board.**
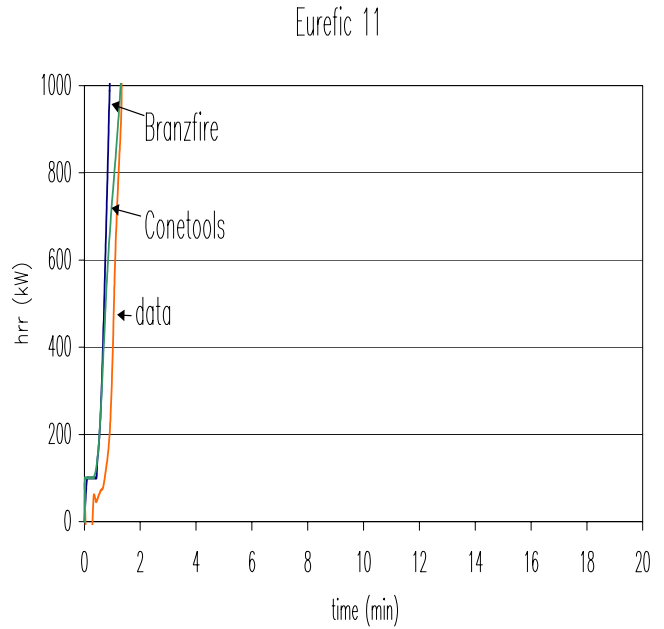


**Figure 29    FR polystyrene foam.**

# The SBI research project
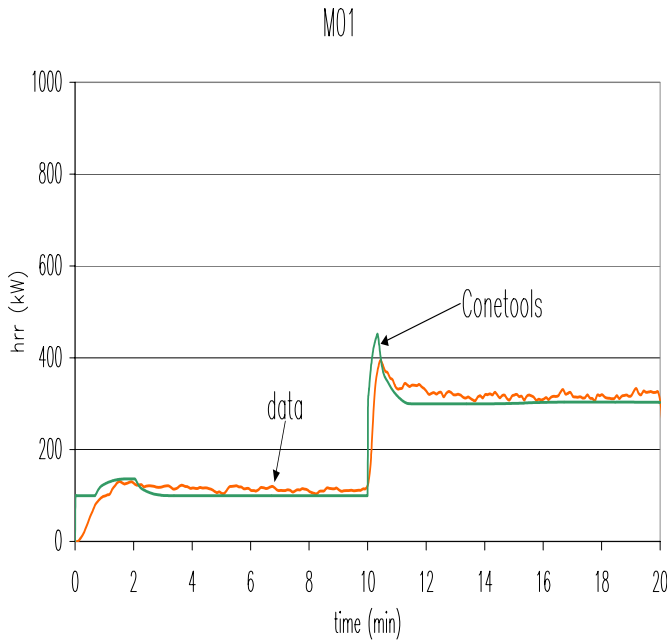


**Figure 30    Plasterboard.**
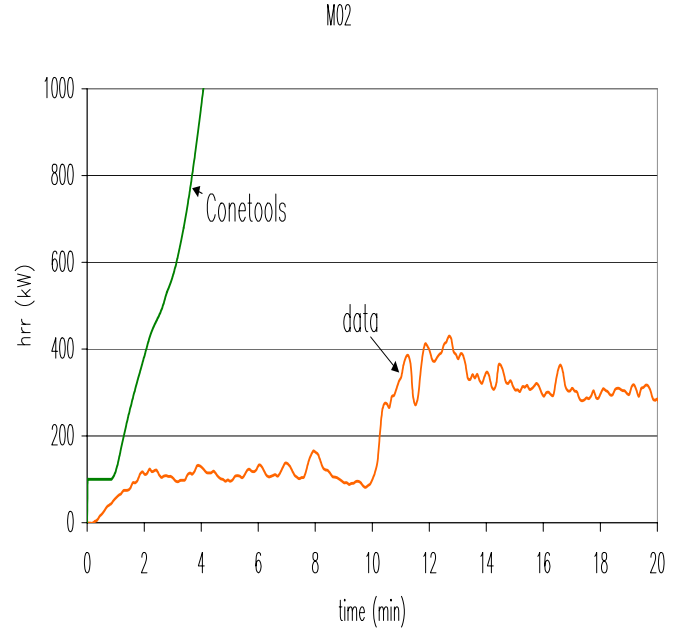


**Figure 31    FR PVC.**
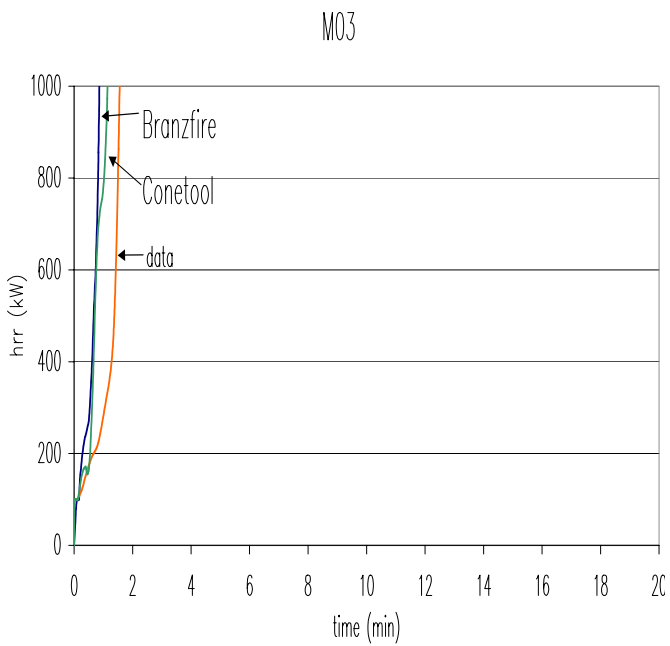


**Figure 32    FR extruded polystyrene board.**
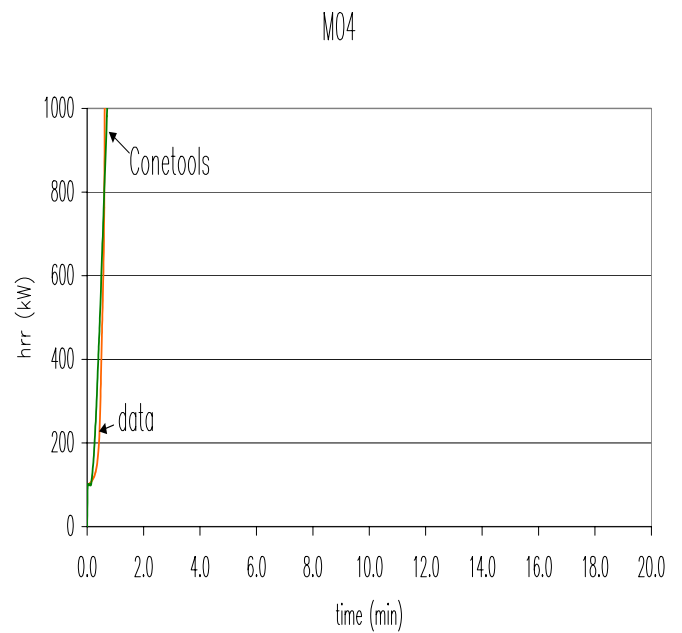


**Figure 33    PUR foam panel with alu foil faves.**
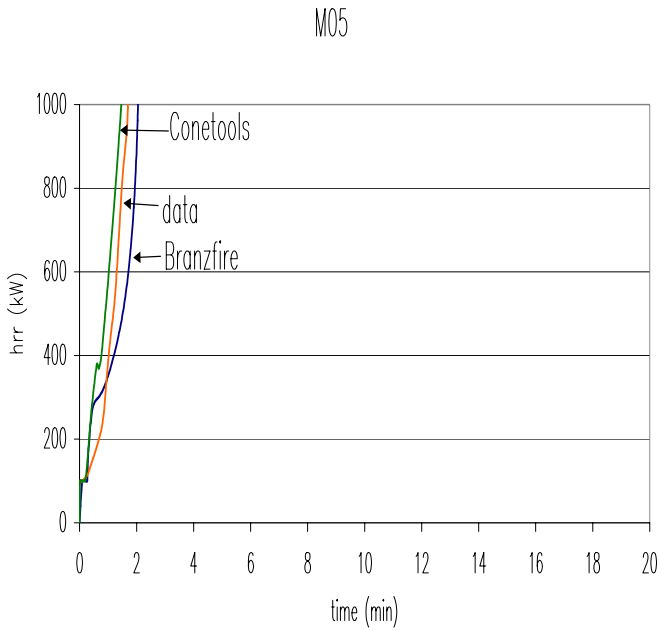
**Figure 34    Varnished mass timbre, pine.**
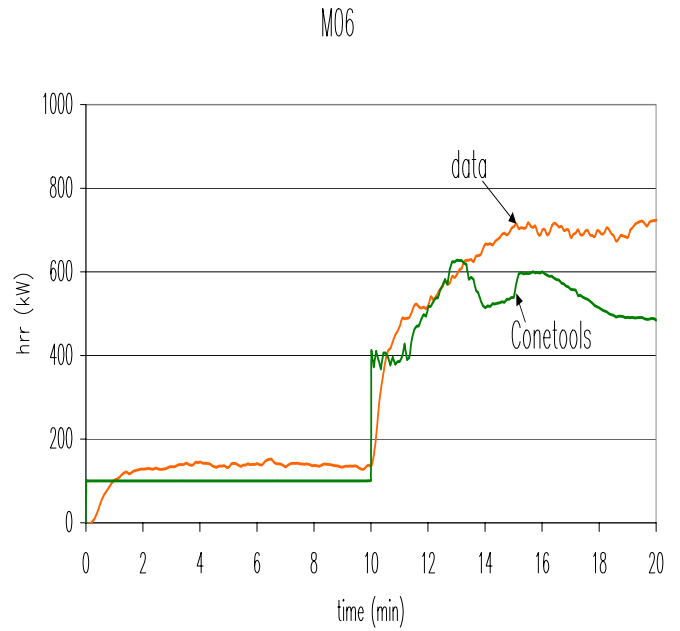


**Figure 35    FR chip board.**
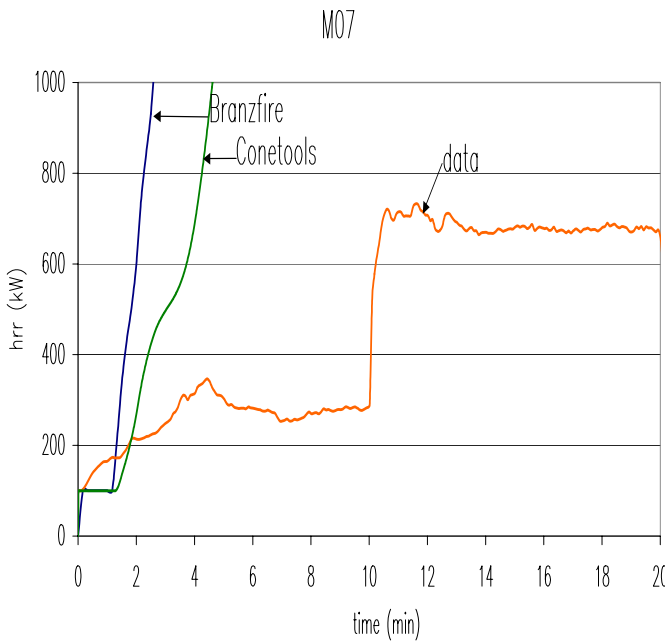


**Figure 36    FR polycarbonate panel 3.**
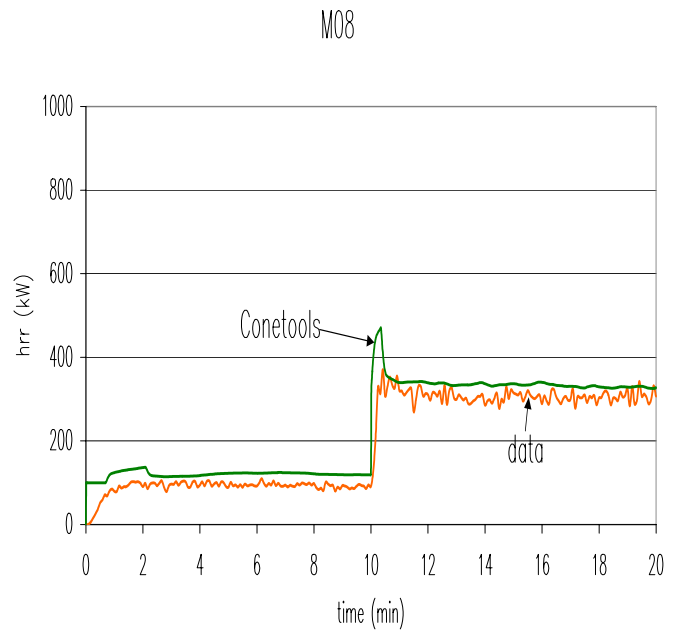


**Figure 37    Painted plasterboard.**
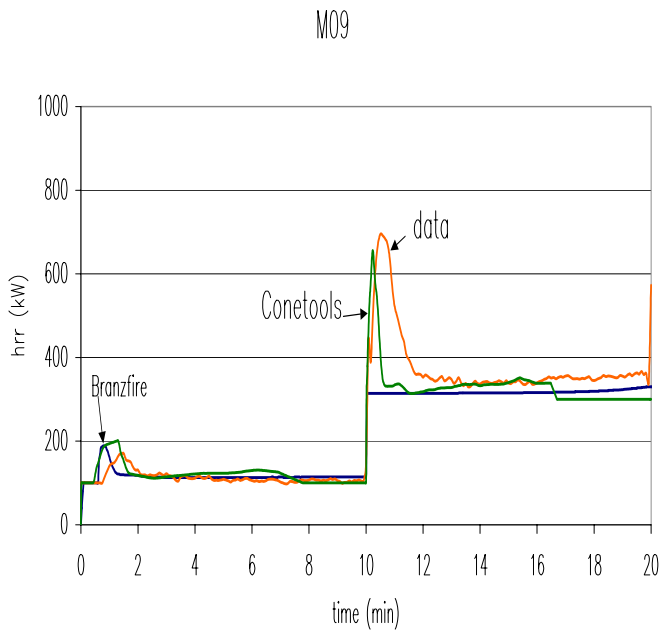
**Figure 38    Paper wall covering on plasterboard.**
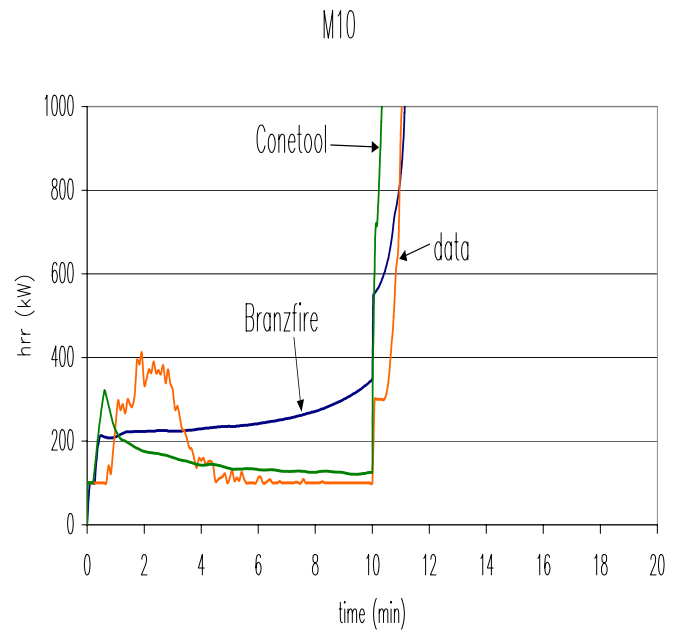


**Figure 39    PVC wall carpet on gypsum plasterboard.**
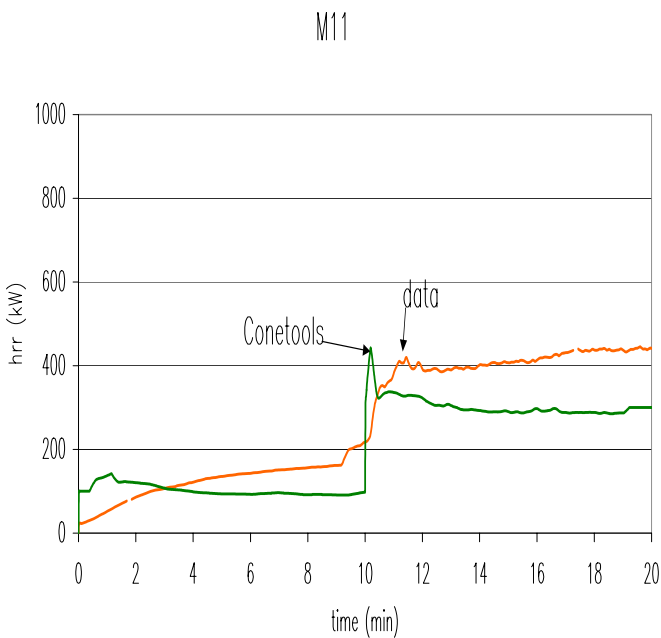


**Figure 40    Plastic-faced steel sheet on mineral wool.**
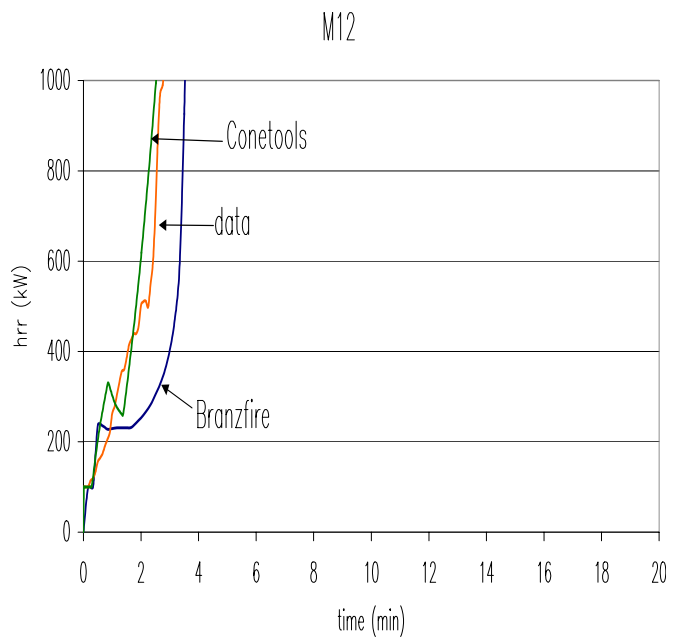


**Figure 41    Unvarnished mass timbre.**

M13
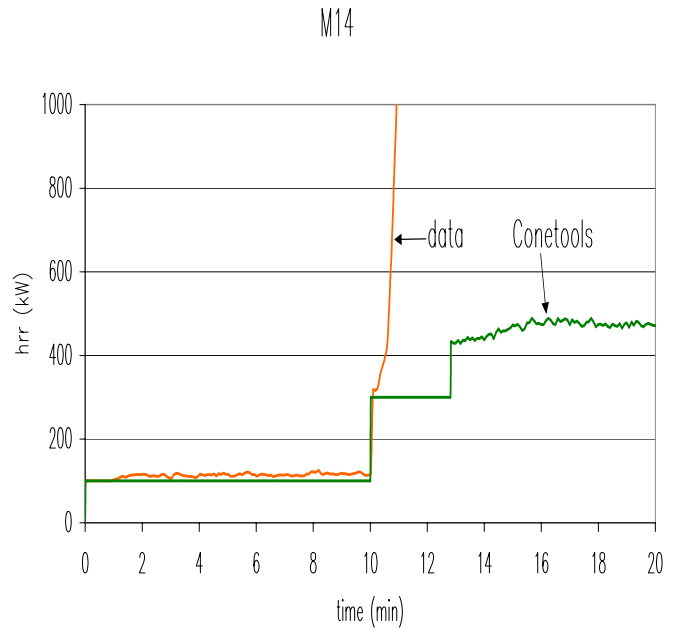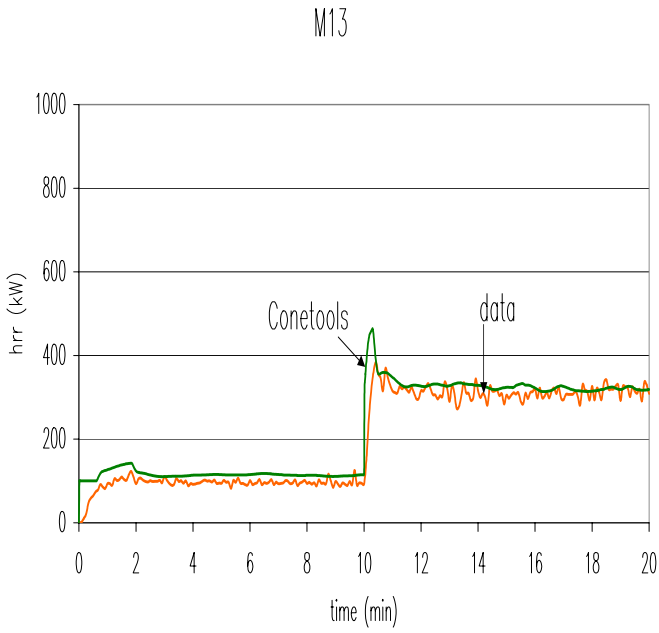


**Figure 42    Plasterboard on polystyrene.**

M14



**Figure 43    Phenolic foam.**

M15



**Figure 44    Intumiscent coat on particle board.**

M16
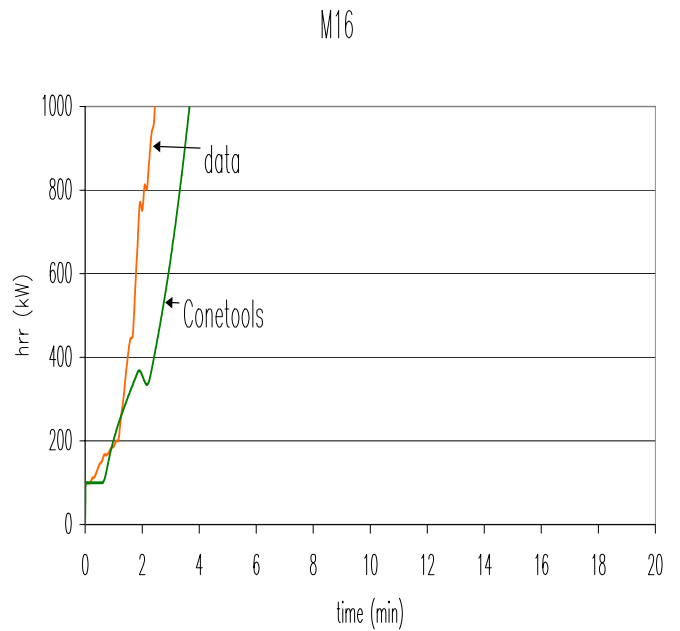


**Figure 45    Melamine faced MDF board.**

M19
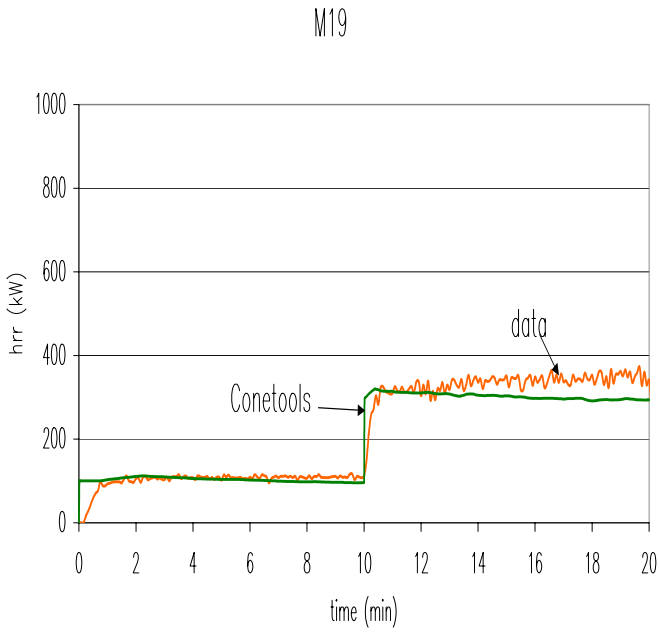


**Figure 46    Unfaced rockwool.**

M20
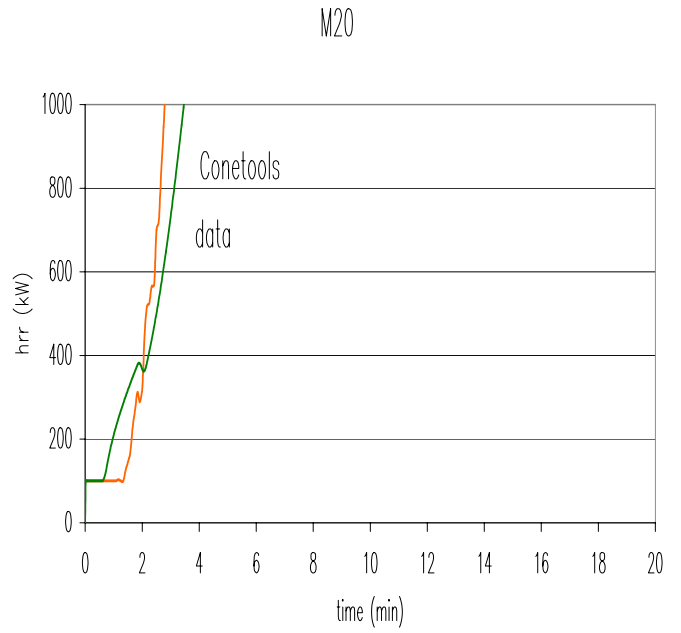


**Figure 47    Melamine faced particle board.**

M21
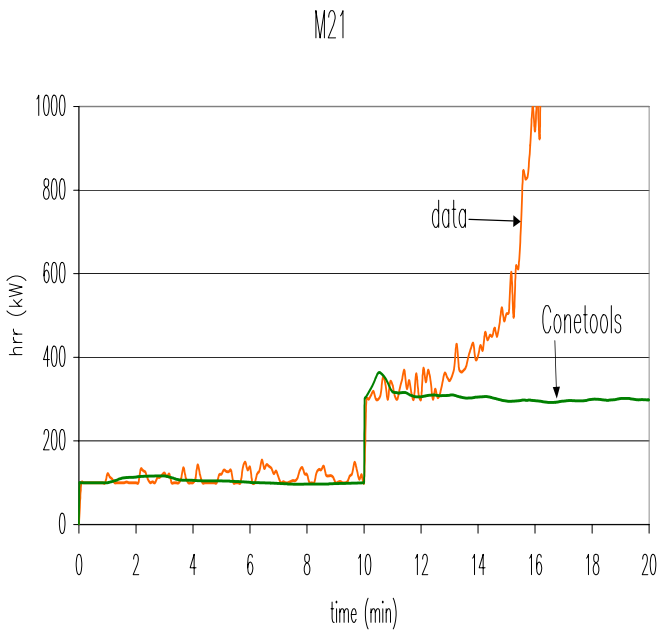


**Figure 48    Steel clad expanded polystyrene sandwich panel.**

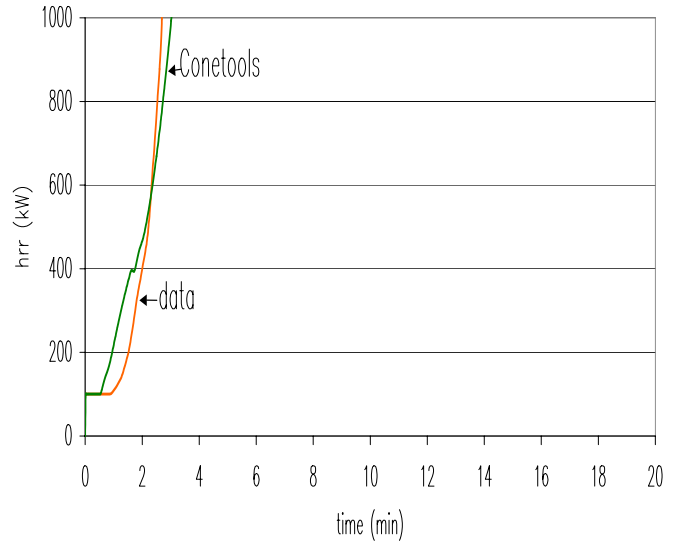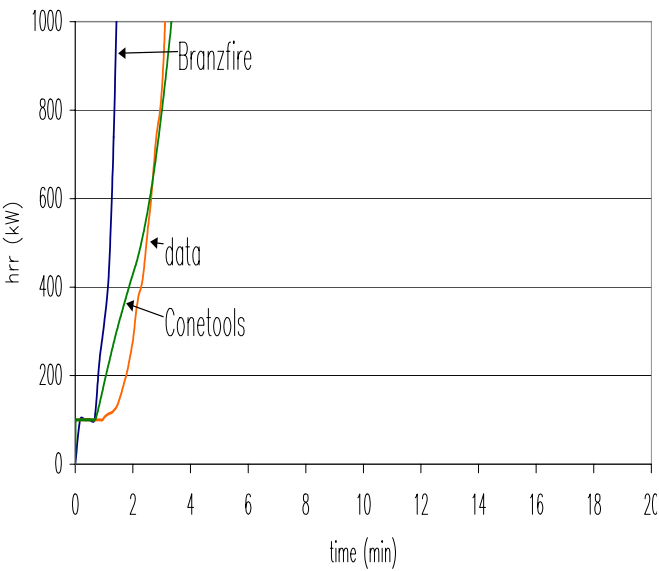M22
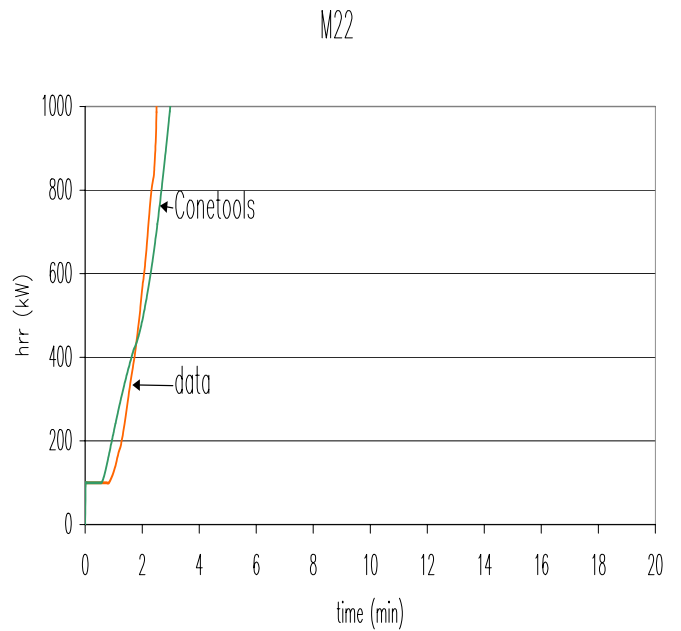


**Figure 49    Ordinary particle board.**
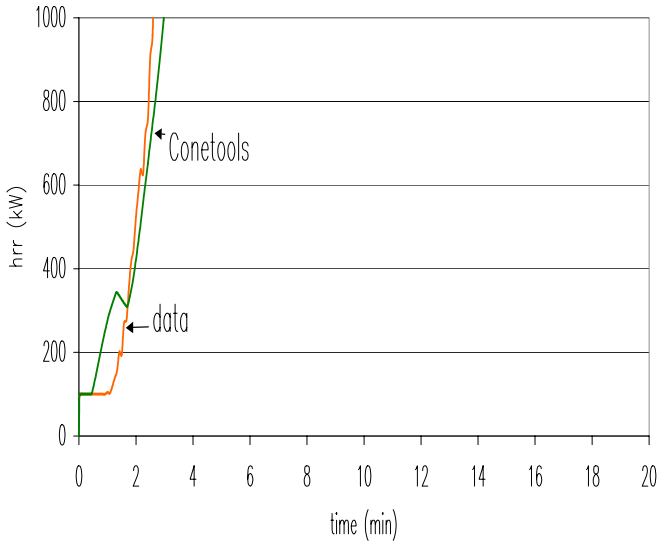
**Figure 50    Ordinary plywood (Birch).**
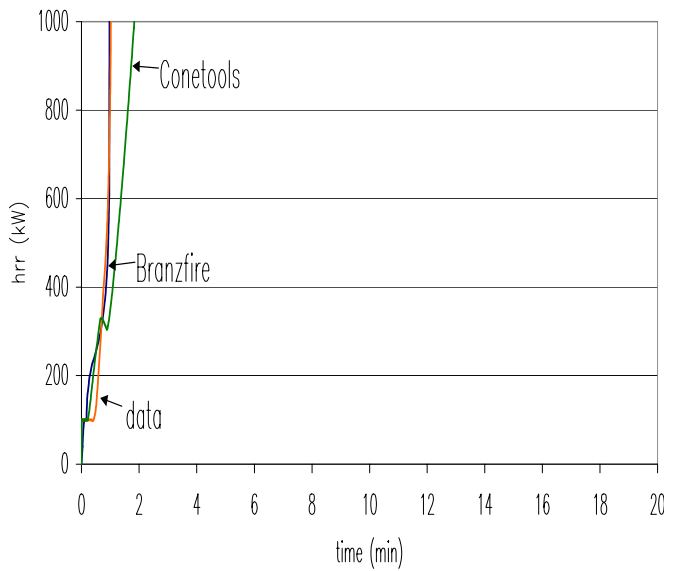


**Figure 51    Paper wall covering on particle board.**
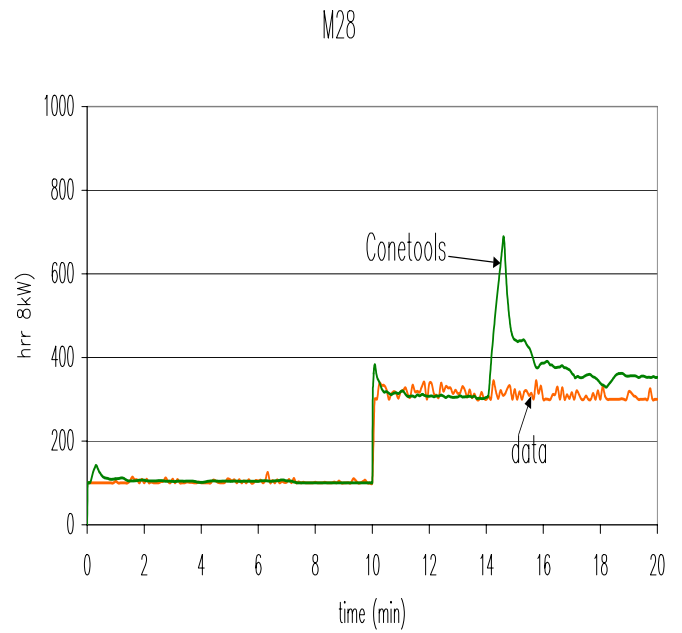


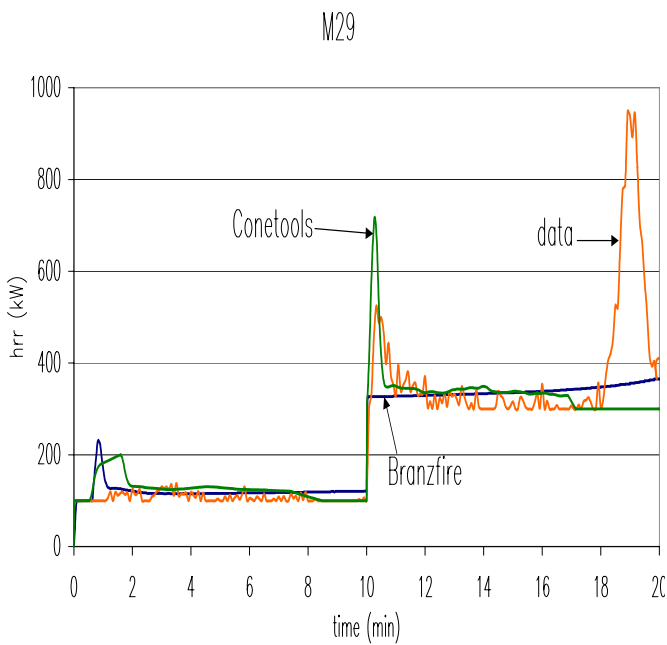**Figure 52    Medium density fibre board.**
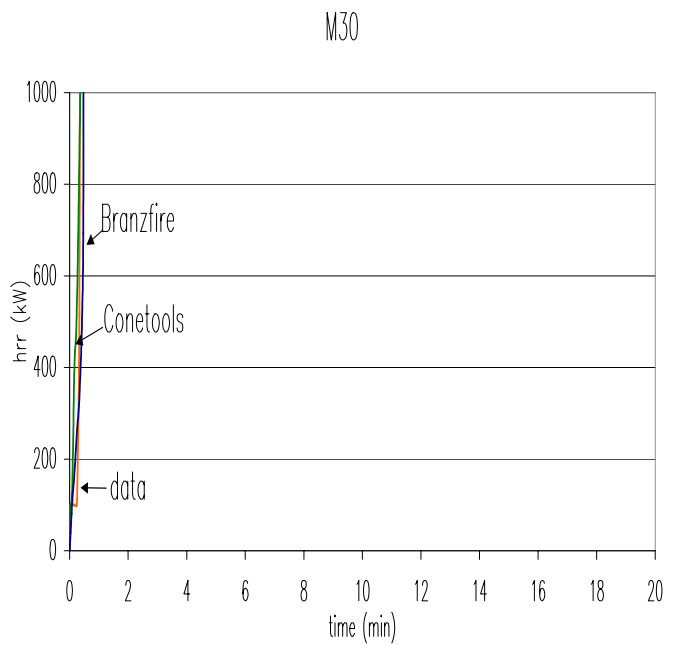


**Figure 53    Low density fibre board.**

**Figure 54    Plasterboard/FR PUR foam core.**



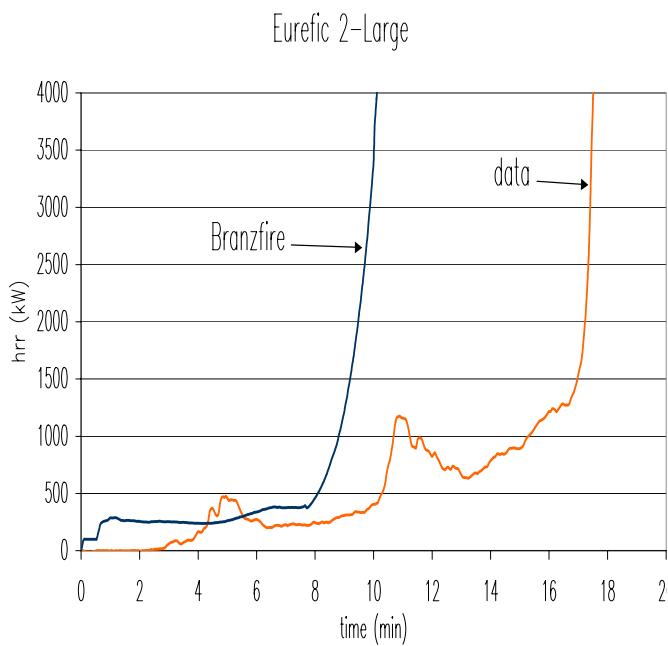**Figure 55    Acoustic mineral fibre tiles.**



**Figure 56    Textile wall covering on calcium silicate board.**



**Figure 57    Paper-faced glass wool.**

## EUREFIC Large scale

Eurefic 2-Large



**Figure 58    Ordinary Birch plywood.**

Eurefic 3-Large
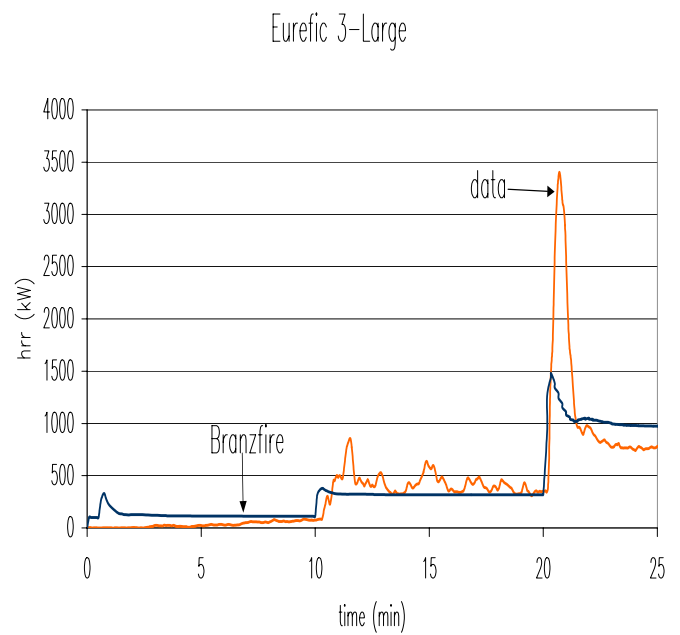


**Figure 59    Textile wall covering on gypsum paper plasterboard.**

Eurefic 6-Large
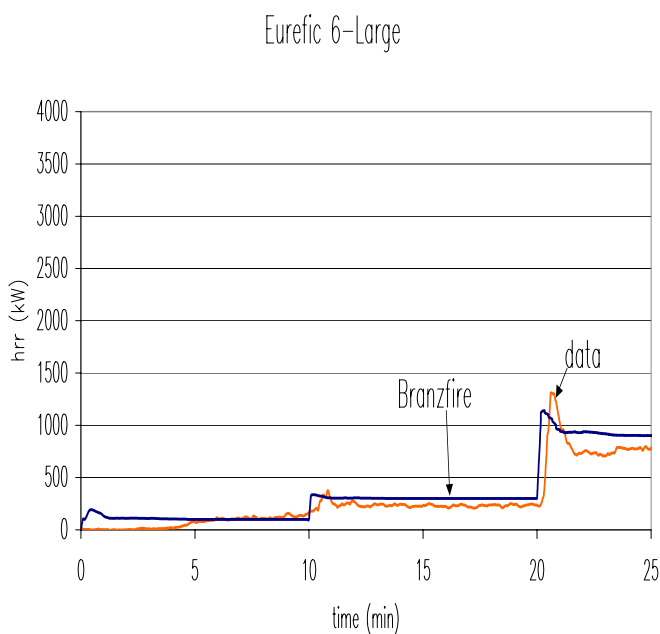


**Figure 60    FR particle board type B1.**

Eurefic 7-Large
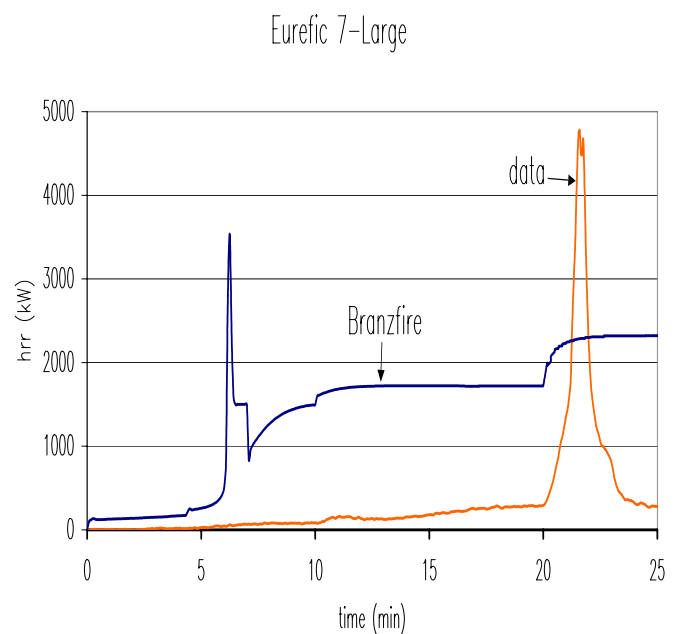


**Figure 61    Combustible faced mineral wool.**
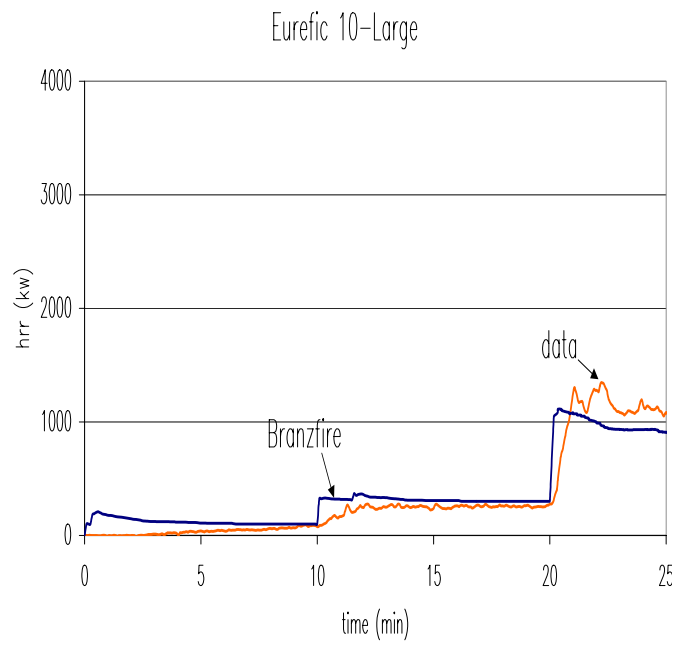
**Figure 62    Ordinary Birch plywood.**

## 600 °C

Measured armchair-hrr
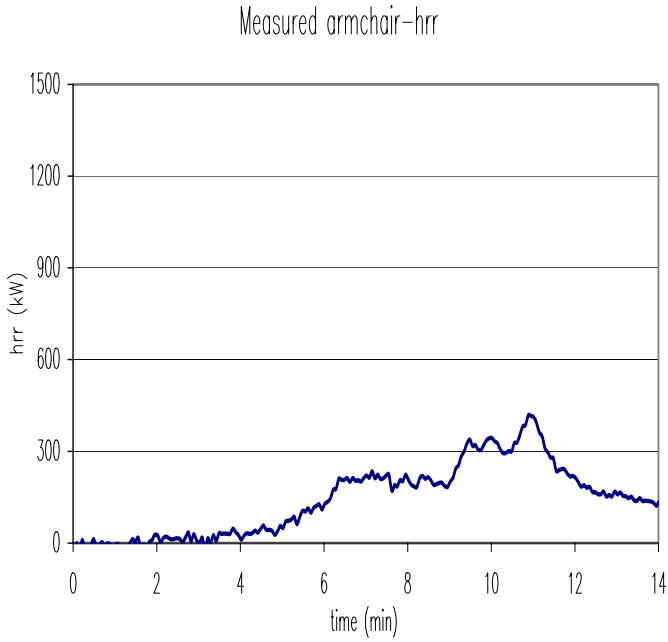


**Figure 63    600°C experiment.**

Temperatures, Euroclass B lining experiment
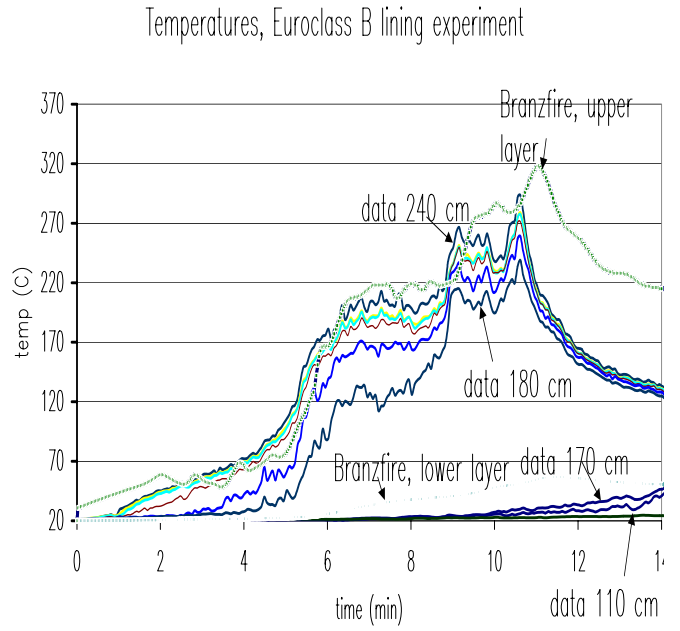


**Figure 64    600°C experiment.**

Simulated neutral plane. Euroclass B linings



**Figure 65    600°C experiment.**

Hrr, Euroclass D lining experiment.



**Figure 66    600°C experiment.**

Temperatures, Euroclass D lining experiment.



**Figure 67    600°C experiment.**

Simulated neutral plane. Euroclass D linings



**Figure 68    600°C experiment.**

Hrr, Euroclass D lining, 30kW-experiment.



**Figure 69    600°C experiment.**

# Annex B   Cable fires

In the FIPEC project [31] two work packages dealt with investigating parameters influencing cable behavior. Some of the FIPEC results from the investigation are summarized here.

## Real scale tests

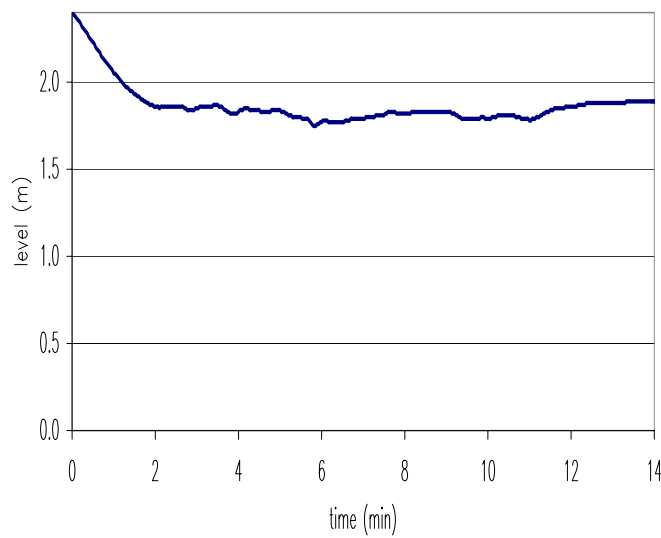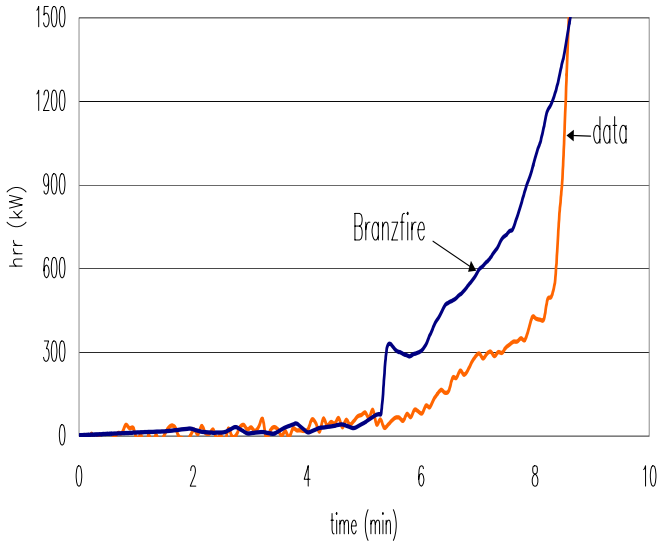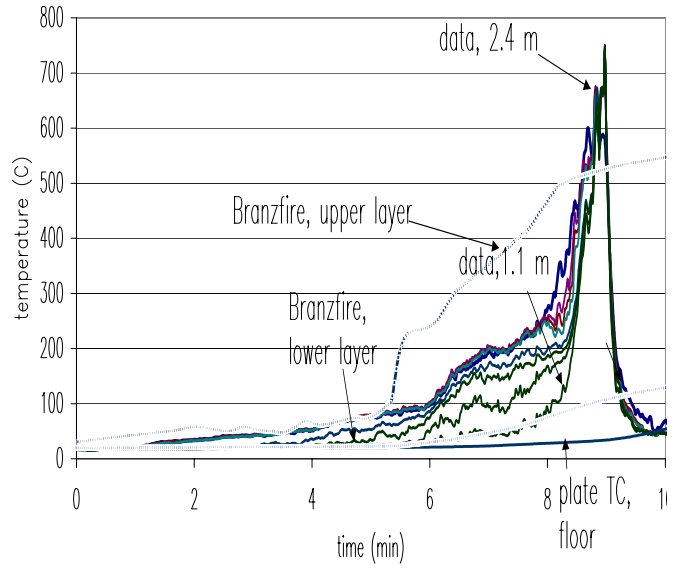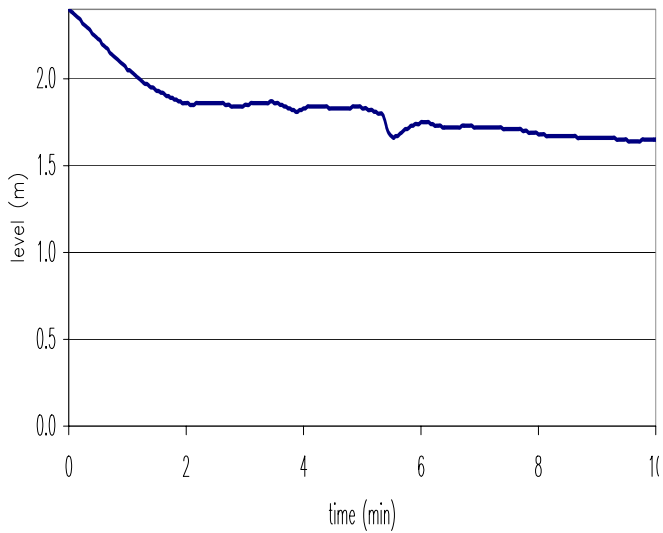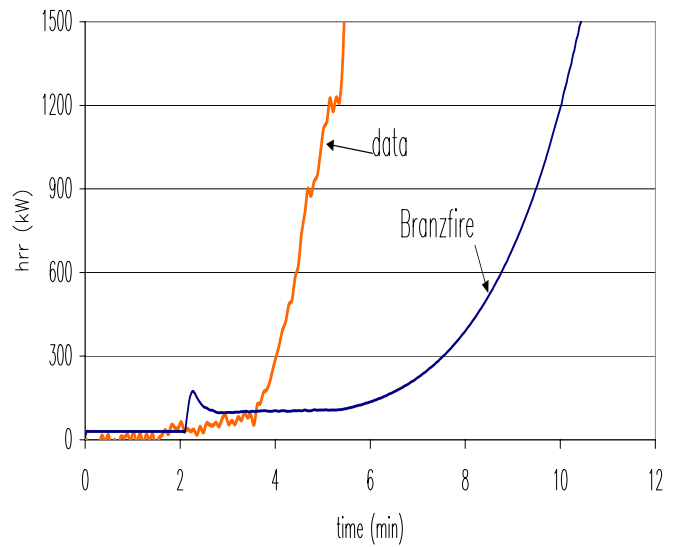In the FIPEC project a review was made which identified a number of real-scale scenarios:

**Table 5**     **Overview of real-scale scenarios.**

| Scenario | Type of cables and numbers | Typical ignition sources | Code |
|---|---|---|---|
| **Power Plants** | | | |
| Horizontal cable galleries | P: >50 DIW: >1000 OC: >10 | Paper waste fire oil spill fire | P1 |
| Vertical cable shafts | P: >50 DIW: >1000 OC: >10 | Paper waste fire oil spill fire | P2 |
| Vertical against walls | P: >50 DIW: >1000 OC: >10 | Paper waste fire oil spill fire | P3 |
| **Tunnels** | | | |
| Horizontal along walls | P: >50 DIW: >100 OC: >5 | Paper waste fire oil spill fire | T1 |
| Horizontal under ceiling | P: >50 DIW: >100 OC: >5 | Paper waste fire oil spill fire | T2 |
| Vertical against wall | P: >50 DIW: >100 OC: >5 | Paper waste fire oil spill fire | T3 |
| **Vehicles** | | | |
| Horizontal under floors | P: >5 DIW: >100 | Paper waste fire oil spill fire | V1 |
| Horizontal and vertical between walls and ceilings | P: >5 DIW: >1000 | Paper waste fire, oil spill fire | V2 |
| **Occupancies** | | | |
| Horizontal non-ventilated voids (floors and ceiling) | P: >100 DIW: >1000 OC: >100 | Paper, furniture, waste fire | O1 |
| Vertical in shafts | P: >100 DIW: >1000 OC: >100 | Paper furniture waste fire | O2 |

**Legend to table**

P = Power cables (Medium and low voltage), DIW = Data and instrumentation cables and wires, OC = Optical cables

From literature and data generated in several full-scale fire projects one can compare the energy in the typical ignition sources. Newspaper fires are approximately 20 to 40 kW. A limited waste fire or limited furniture fire can quickly reach 100 kW. Oil spill fires quickly achieve 300 kW and more.

The major installation scenarios can be divided into horizontal and vertical configurations. A further division is based on whether or not there is thermal feedback from an adjacent surface (wall, floor, and ceiling). Hence three subdivisions can be made, which are termed open, semi-closed and closed. The closed configuration can be tested with or without forced ventilation. It was also necessary to investigate the void configuration i.e. a set-up where the cables are mounted inside a wall with very limited air access

Table 6 shows how the real-scale test configurations relate to the different key scenarios as given in Table 5.

**Table 6**     **Overview of the connection between test configurations and key scenarios.**

|  | Open | Semi-closed | Closed | Closed with ventilation | Void |
|---|---|---|---|---|---|
| Horizontal | P1 V1 O1 | P1 T1 T2 V1 O2 | P1 T1 T2 V1 O2 | T1, T2 | V2 |
| Vertical | P2 O2 | P3 T3 O2 | P2 T3 O2 | T3 | V2 |

## Results of Comparative Tests

### (a)  Horizontal Scenarios

*Comparison of the Heat Source Programme in the open Horizontal Scenario*

The heat release rate curves for one cable (Cable A) tested with three different heat sources in an open horizontal scenario are shown in Figure 70. It can be seen that a 20 kW heat source causes little effect and even a 40 kW heat source causes only limited heat release rate from the cables. Incident heat levels of at least 100 kW, and especially 200 and 300 kW are needed to obtain a significant measurable heat release rate contribution from the cables. The cable contribution to the heat release rate at the 100 kW input level is identical for heat source programmes 2 and 3. This means that the 5 minutes preheating period at 40 kW in heat source programme 3 only had a minor effect. It is important to note that: (a) no flame spread was observed with cable A, even at heat input levels up to 300 kW and (b) after a short period of HRR increase, the HRR decreased again, and returned towards the heat release level of the heat source. Considering these points, heat source programme 3 was chosen for subsequent tests, in order to observe at which heat source levels flame spread would occur. The strategies explained above (relating to the increase of the heat release level and the specimen extinguishment) were applied for all remaining tests. Hence some tests were stopped before the end of the 25 minute burner exposure programme.
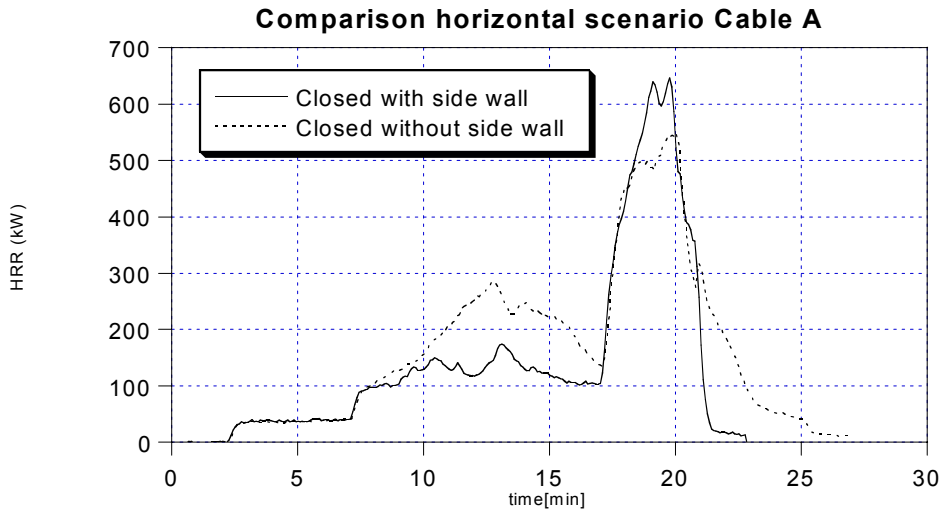
**Open Horizontal Scenario Cable A**
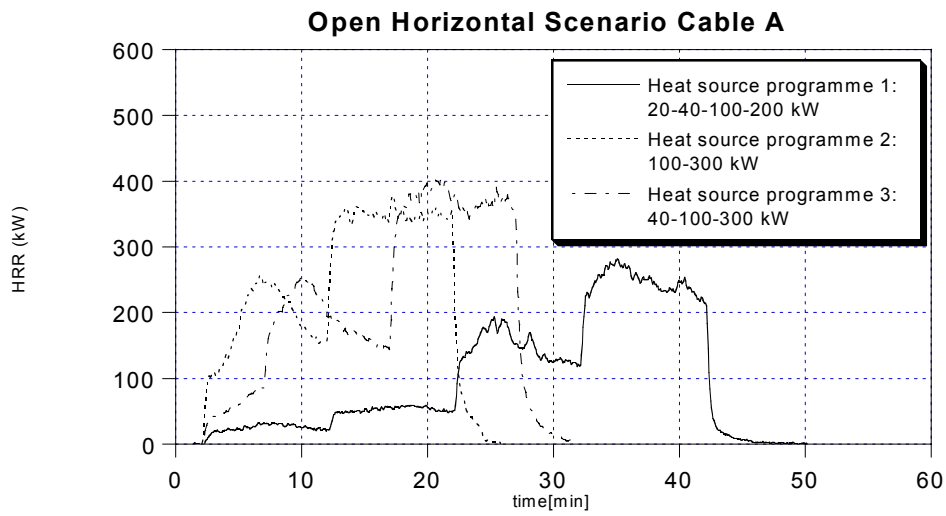


**Figure 70**  **Comparison of different heat sources in the open horizontal scenario.**

*Comparison of Different Horizontal Configurations Without Ventilation*

**Comparison horizontal scenario Cable A**
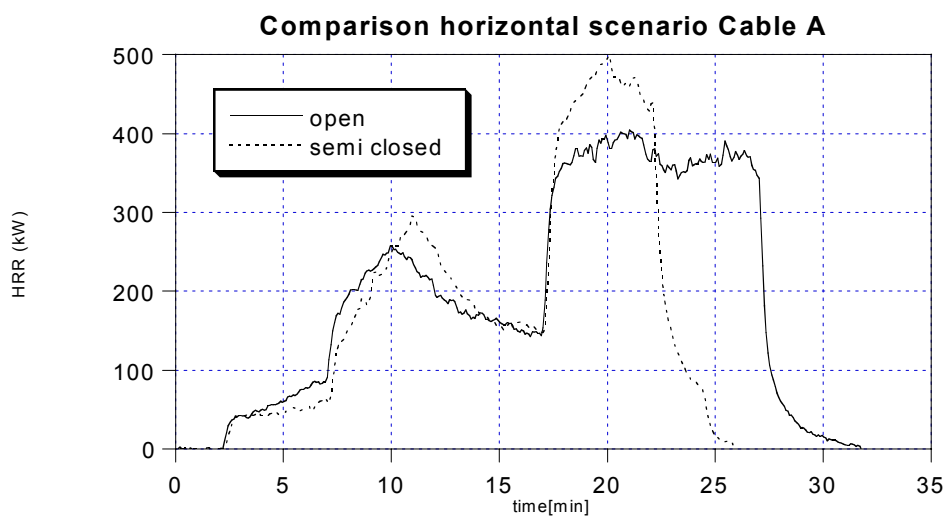


**Figure 71  Comparison of open/semi-closed horizontal scenarios for cable A.**

## Comparison horizontal scenario Cable A



**Figure 72    Comparison of closed horizontal scenarios for cable A.**

It is clear from Figure 71 that the semi-closed configuration generates more heat release than the open configuration. Furthermore, it can be seen in Figure 72 that the closed configuration shows clear evidence of flame spread for Cable A at the 300 kW input level (i.e. 15 minutes from the start of heat source exposure = 17 minutes on the graph). In the closed configuration, without endwall, there was some limited flame spread at 100 kW. Inclusion of the partial vertical endwall to limit ventilation in the upper section of the rig delays the onset of the flame spread until the 300 kW burner level is applied. This could be seen during the test, since the upper cable tray did not ignite as fast, probably due to a lack of oxygen in the corner where the walls and ceiling meet. Once the 300 kW level is reached both closed configurations produce very similar results.

## Comparison horizontal scenario cable C
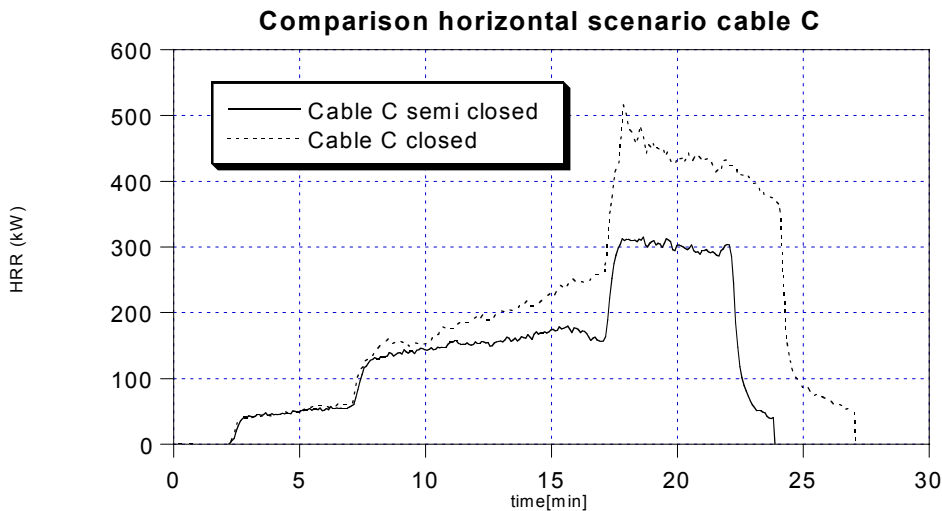


**Figure 73    Comparison of horizontal scenarios for cable C.**

**Comparison horizontal scenario cable D**
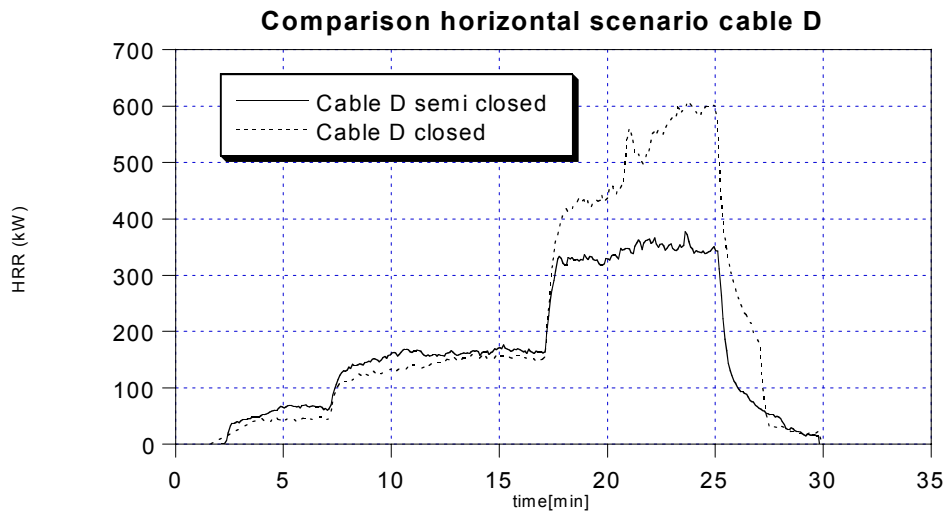


**Figure 74    Comparison of horizontal scenarios for cable D.**

Test results on Cables C and D, given in Figure 73 and  Figure 74, show similar trends to cable A. Clearly, the closed scenario is more severe than the open one and leads to flame spread for these cables, as it had done for Cable A. In the case of these cables (C and D), there is no evidence of either flame spread or substantial heat contribution at the 100 kW level.

*Comparison of Cables in Horizontal Closed Configurations With Forced Ventilation*

**Horizontal scenario ventilation effect Cable B**



**Figure 75    Comparison of closed horizontal scenarios for cable B.**

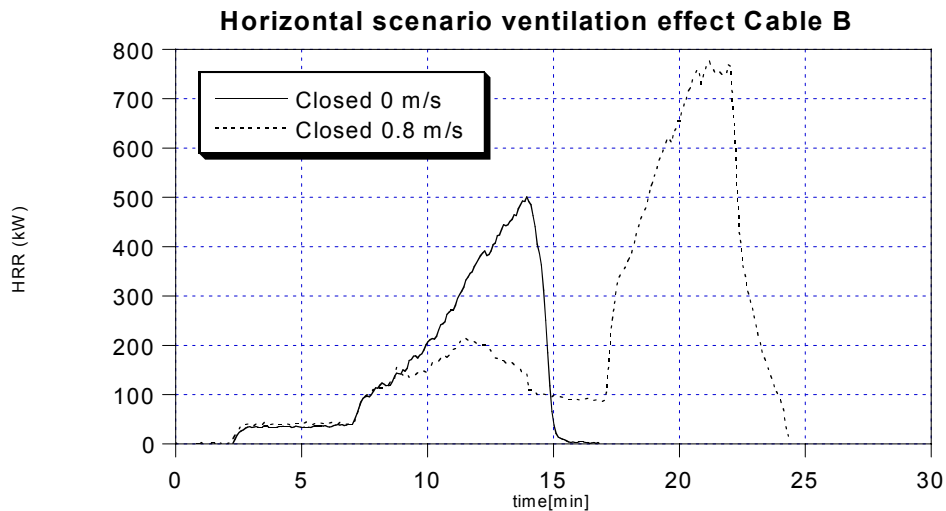The effect of forced ventilation in the closed horizontal scenario was investigated with Cable B. Figure 75 shows that increased ventilation results in non propagating flame spread at the 100 kW level and hence the non-ventilated test is a lot more severe. This non-ventilated test (0 m/s) shows a propagating flame spread which had to be extinguished after 15 minutes (13 minutes burner application). When the ignition source was increased to 300 kW in the forced ventilation (0.8 m/s) test, the cables showed faster flame spread rates than the non-ventilated test had exhibited at the 100 kW level but one should

realise that the thermal attack is higher in this case. Also the test with forced ventilation (0.8 m/s) had to be stopped before the end of the heat source programme.

Peak HRR values between these two tests should not be compared because

1.  HRR from the burner is included in the graphs

2.  the fire had to be extinguished for safety reasons in both case hence the maximum value of HRR is unknown

It can be concluded that one should not always expect that a ventilated scenario is the most severe condition. The non-ventilated test showed a propagating flame spread at a much lower heat source level than the ventilated test.

*Comparison of Cables in the Different Horizontal Configurations*
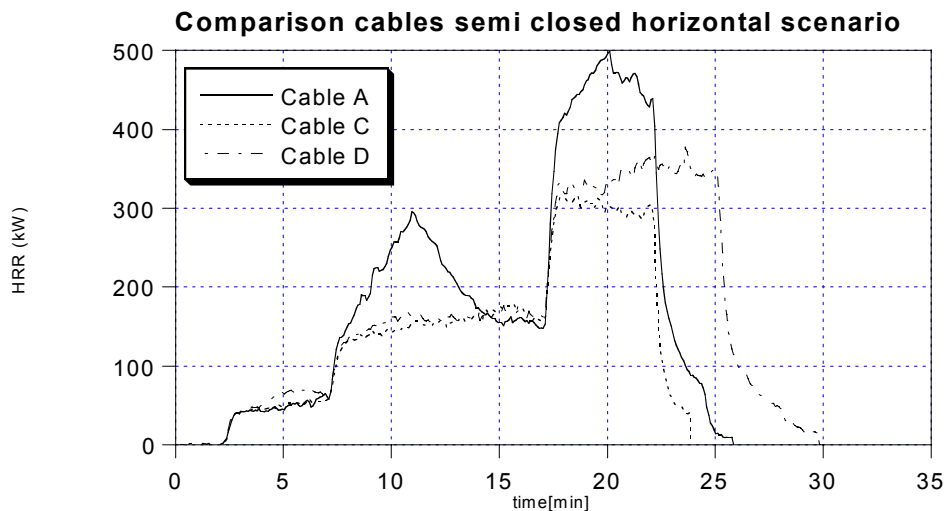


**Figure 76    Comparison of cables in the semi closed horizontal scenario.**

Test results for three different cables, in the semi-closed horizontal scenario, are shown in Figure 76. Cables C and D generate very similar results, and out-perform cable A, which spreads flame significantly faster. This scenario was considered to be inadequate for distinguishing the fire performance of cables.

**Comparison cables horizontal closed**
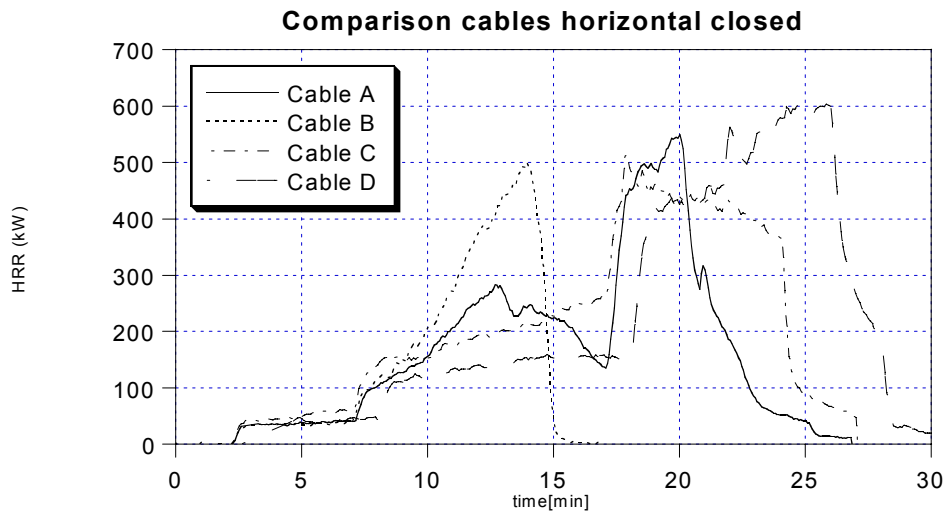


**Figure 77    Comparison of cables in the closed horizontal scenario.**

The test results for all four cables in the closed horizontal scenario are shown in Figure 77. The flame spread from Cable B is the fastest, followed by Cable A. Cables C and D perform similarly to one another in the 100 kW phase, but they can be differentiated, albeit not by much, at the 300 kW level, where cable D has more flame spread. In consequence, this closed scenario is adequate for generating distinctions between the cables.

## (b)  Vertical Scenarios

*Comparison of Different Vertical Configurations Without Ventilation*

**Comparison vertical scenario Cable B**
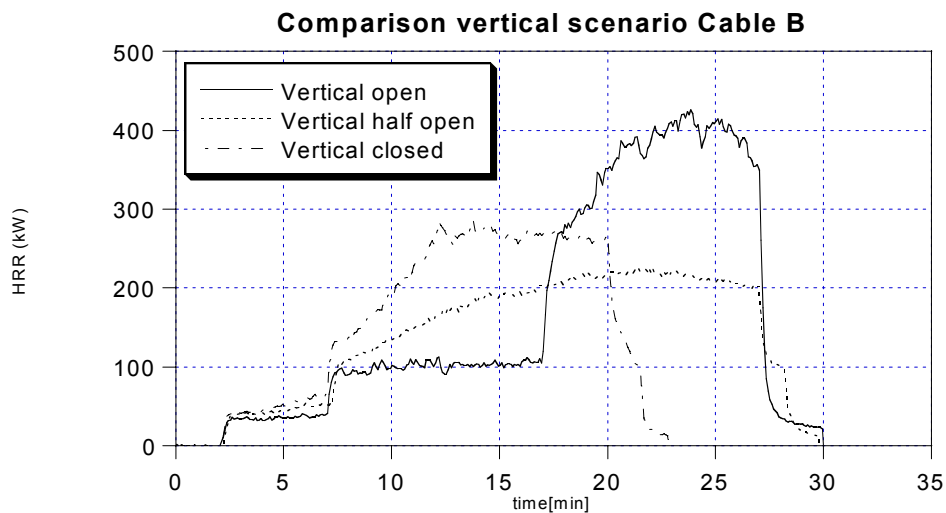


**Figure 78    Comparison of vertical scenarios for cable B.**

Three vertical configurations were investigated with Cable B and the results are shown in Figure 78. The cable chosen was the one with the poorest fire performance in Figure 77. In the first test (open configuration) two parallel cable trays were mounted, but no lateral flame spread (between trays) was

observed. As there had been no inter tray flame spread for this poor performance cable it was judged unlikely to occur in others and hence only one vertical cable tray was used for the remaining tests to avoid excessive use of cables.

It can be seen that no flame spread occurs in the open configuration at the 100 kW burner level. Flame spread was observed at the 100 kW level both in the semi-closed vertical configuration (one corner situation) and in the closed vertical configuration.

Note that

1.   the heat release rate levelled out in the closed configuration once the whole tray was burning; and

2.   the fire is clearly ventilation-controlled in this configuration due to the closed set-up.

*Comparison of Cables in the Vertical Closed Configuration With Forced Ventilation*



**Vertical scenario ventilation effect Cable B**

Legend:
- Closed 0 m/s
- Closed 0.6 m/s
- Closed 1 m/s
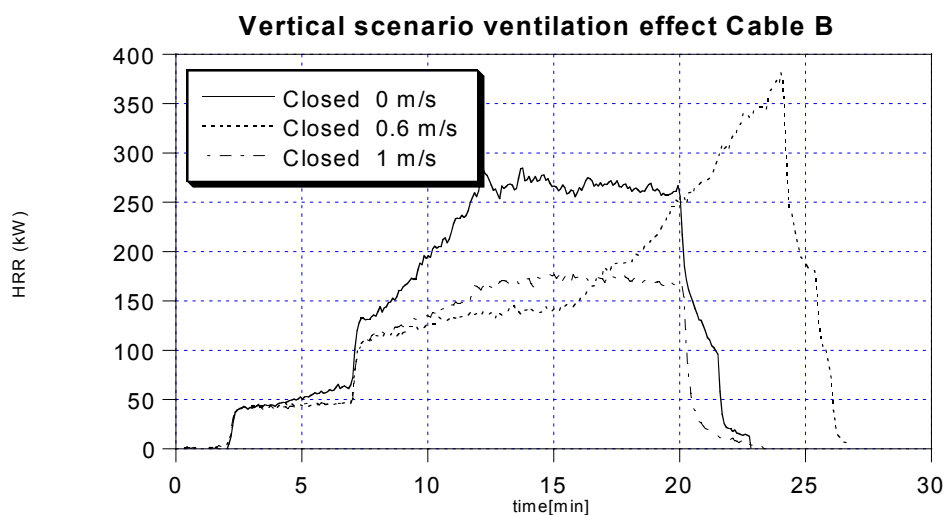
**Figure 79    Comparison of vertical closed scenarios with ventilation for cable B.**

The effect of forced ventilation was studied in the vertical closed scenario with Cable B, and the results are shown in Figure 79. It can be observed that increasing the ventilation to higher airflow rates does not have large effects on flame spread in this set-up. It should be noted that  installation of cables in forced ventilation shafts is rare in Europe.

*Comparison of Cables in the Different Vertical Configurations*

Tests with all four cables in the semi closed vertical configuration are shown in Figure 80. It is clear that the behaviour of the cables differ. Cables A and C spread flames first. Cable B takes longer and cable D is the slowest. All four cables showed a clear flame spread at the 100 kW heat input level, which demonstrated that this scenario was more severe than the horizontal scenario. It can also be seen that the semi-closed or corner configuration is capable of distinguishing between the fire performances of the cables even when the same burner level initiates flame spread.

**Comparison cables in semi closed vertical scenario**
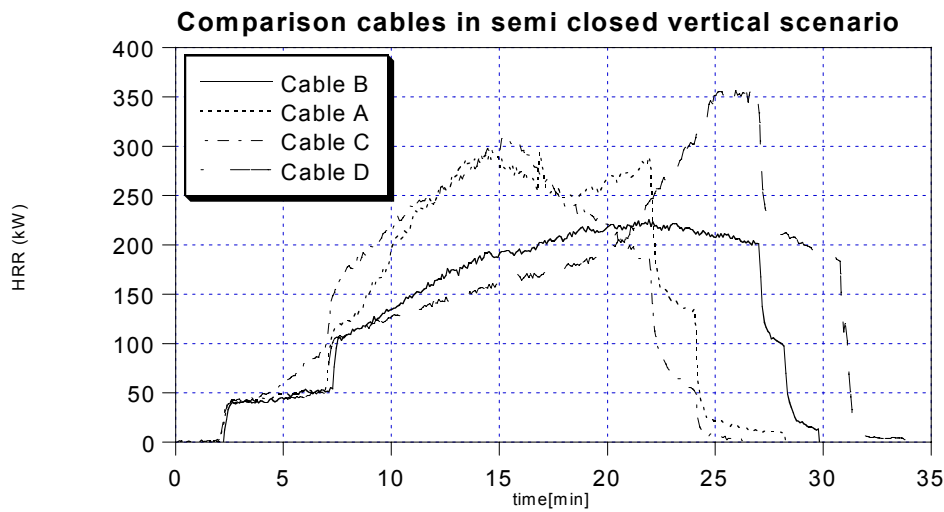


**Figure 80    Comparison of cables in the semi-closed vertical configurations.**

## (c)  Void Scenarios

In the void scenarios it was seen that a vertical void is definitely more severe than a horizontal void. A heat source similar to the IEC 60332-3 [32] test produces a continuous flame spread on cable C, which can be considered as a high performance cable. Although only a few tests were conducted it is clear that some consideration should be given to a vertical void scenario, where re-radiation and chimney effects play very important roles. The results of the vertical void scenario test are given in Figure 81. The length of the cable was limited to 1 m, but even at such a short length a HRR of 100 kW is observed (note that the burner level was only 20 kW in this test scenario). The horizontal void scenario test on the same cable did not show any heat release contribution from the cable.

**Vertical void scenario cable C**
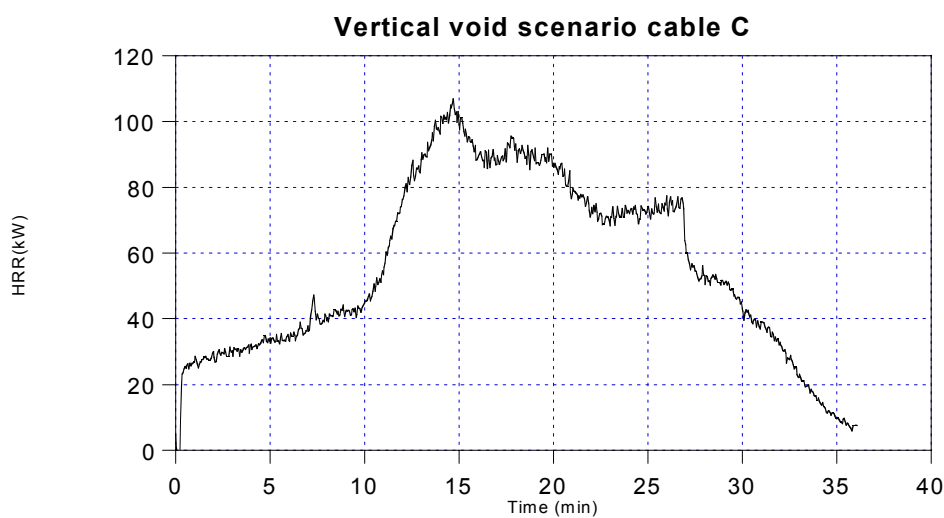


**Figure 81    Vertical void scenario.**

# Discussion

Fire development in vertical situation is faster than in horizontal situation for the same type of configuration.

Cables positioned in closed voids will spread fire faster than in an open configuration

Flame spread will depend on the level of thermal attack

Ventilation is a critical parameter which also is difficult to handle. The recent research conducted does not give a conclusive answer on this item Recent studies on communication cables showed that cables fires in ventilated areas (e.g. plenums) can be more dangerous and constitute a serious risk. But the FIPEC project showed that ventilation does not always means more critical conditions.

## Suggestions for further work

Check whether similar approaches as for wall and ceiling linings are possible by using models which allow a flexible use of the design fire. A first approach is studied in the Brandforsk project "Flame spread of cables in difficultly accessible areas"

**References**

[31] *FIPEC, Fire Performance of Electric Cables,* Report, European Commission SMT Programme, SMT4-CT96-2059

[32] IEC 60332-3 –*Tests on electrical cables under fire conditions* – International Electrotechnical Commission, Geneva, 2000

# Annex C   Combustible electronics

One important contribution to fire risks in buildings is the increased use of different electronic equipment such as computers, printers and monitors/TV-sets. It might therefore be of interest to see how these devices behave when ignited. They represent what has earlier been refered to as point sources in an enclosure fire and they are of cource of vital importance for development of fires. In this appendix, recent tests made on such devices are reported. The information given below is gathered from four different research reports [33,34,35,36]. For a more detailed picture, these sources are recommended.

## Printer data

See [34] for the full report.

Hewlett Packard HP 690C Deskjet: HP inkjet printer, model number C4562A. CE marked. Purchased in Sweden. The enclosure material passed HB classification according to UL 94.

Lexmark Z11 Deskjet: Lexmark inkjet printer, machine type 4100 S01. CE and UL marked. Purchased in Sweden. The enclosure material passed HB classification according to UL 94.

### Ignition source

The ignition source used in the tests was a methenamine pill. This source, which is equivalent to a small open flame and is sometimes used to simulate an internal ignition, is approximately the same size as a match flame and has a duration of approximately 60 seconds at this size. This ignition source was sufficient to obtain ignition in both tests.

### Test configuration

The hood outside of the ISO 9705 room was used for both tests. The printers were weighed during the tests and the mass loss rate (MLR) and heat release rate (HRR) were registered.

### Test results

HP 690C Deskjet: The HP printer had a nominal weight of 5.2 kg. All plastic material appears to have been combusted before the test was terminated. The total amount of combustible material has been estimated to be approximately 2.2 kg based on the mass loss data. The HP printer test was terminated 28 minutes after ignition.
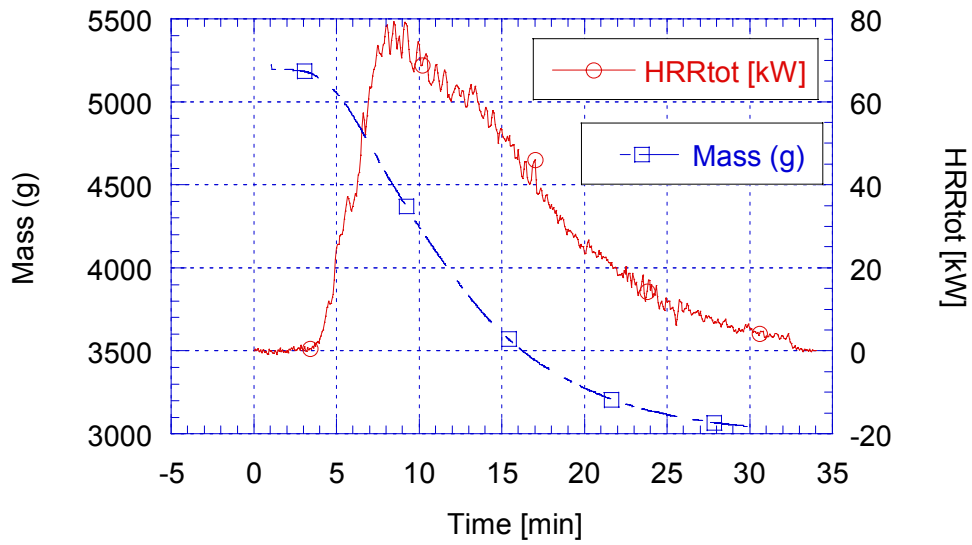
**Figure 82    Heat release rate and mass loss rates for HP 690C Deskjet.**

Lexmark Z11 Deskjet: The Lexmark printer had a nominal weight of 2.3 kg. All plastic material appears to have been combusted before the test was terminated. The total amount of combustible material has been estimated to be 1.3 kg based on the mass loss data. The Lexmark printer test was terminated 27 minutes after ignition.
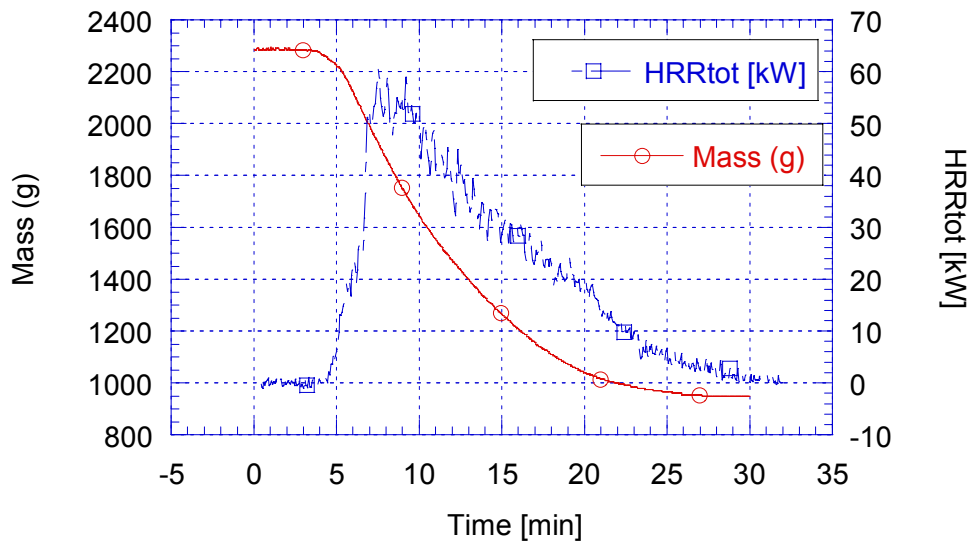


**Figure 83    Heat release rate and mass loss rates for Lexmark Z11 Deskjet.**

# Computer Monitor data

See [33] for the full report.

Flammable monitor: Flammable, failed UL 94 V classification.

### Ignition sources

Match: This ignition source is very small and could correspond to an internal ignition. The duration of ignition is approximately 30 seconds.

### Test configuration

The ISO 9705 room was used for all tests. Furnishing typical for a child's bedroom were kindly donated by IKEA of Sweden. The furnishings conformed to European standards (i.e., not UK standards) for furniture safety. The exact furniture is listed in Table 7 below.

**Table 7      Furniture used in the bedroom experiments.**

| Type of furniture | IKEA product name |
|---|---|
| Bed | Gutvik |
| Mattress | Populär |
| Douvé | Sälg täcke |
| Pillow (2 ×) | Sälg kudde[11] |
| Sheets | Rivig påslakan |
| Curtains | Klämmig gardin |
| Desk | Goliat skrivbord |
| Drawers | Goliat hurts |
| Swivel chair | Svenning |
| Carpet | Jörsby |
| Rubbish bin | Aero papperskorg |
| Diskette holder | Box Diskette hållare |

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[11] This type of pillow was used in the first full room experiment but a similar type was purchased from "Jysk" for the second full room experiment (see the note on the next page).

The approximate floor plan of the room is shown in Figure 84.
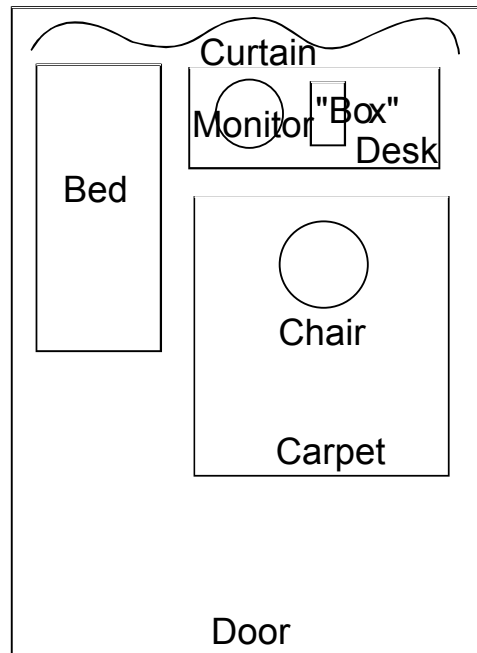


**Figure 84    Schematic floor plan of the test room.**

**Test results**

Flammable monitor: The monitor was easily ignited using a match flame. The enclosure material was tested according to the UL V classification. This material burned for an extended period after removal of the ignition source, burned along the whole length of the specimen, and produced burning droplets. Thus it failed all three V classes (i.e., V0, V1, and V2). The material was not tested according to UL 94 HB classification. As stated above, however, it should comply with IEC 950 which would require that the mechanical enclosure material "shall be of flammability class HB or better". Thus, one can assume that this material conforms to the HB rating.

The convective heat release rate was also measured in this experiment. The results from this measurement are shown in Figure 85. The total heat release measurements failed due to malfunction of the oxygen analyser. Thus, the peak total heat release may be up to twice the value indicated by the convective HRR measurements.
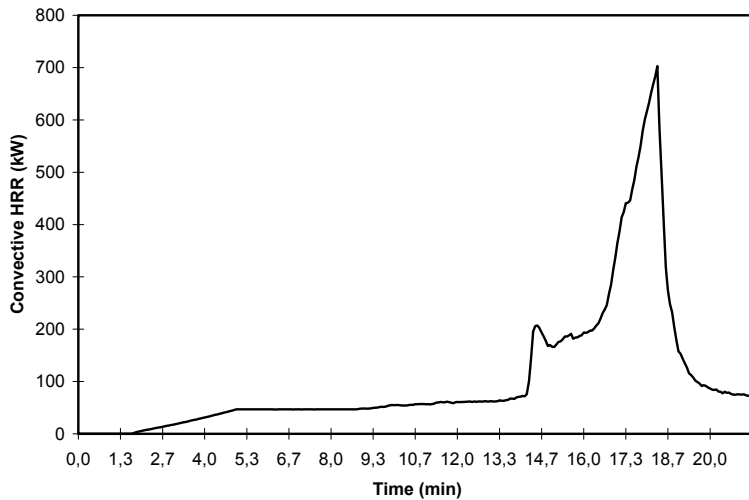
**Figure 85    Convective heat release rate (Convective HRR) in kW from the room test conducted using the flammable monitor.**

## Printer and CPU data

See [35] for the full report[12].

Epson Inkjet Printer: CE marked[13]. Delivery arranged by NASFM. (paper and toner were removed for the purpose of the tests).

HP Pavilion PC: CE and UL (Underwriters Laboratories) marked. Delivery arranged by NASFM.

IBM PC 300PL: CE marked. Delivery arranged by NASFM.

**Ignition source**

The ignition sources used in the tests were a methanamine pill, a tealight sized candle in a tin holder and a paper ball. The candle and paper ball were used on the IBM CPU only as the methanamine pill was sufficient to ignite both the Epson printer and the HP CPU. Each ignition source is described in more detail below.

Methanamine pill: This ignition source is equivalent to a small open flame and is sometimes used to simulate an internal ignition. It is approximately the same size as a match flame and has a duration of approximately 60 seconds at this size.

Candle flame: This ignition source was approximately the same size as the match but represented a continuous ignition source for an extended period of time. The duration of impingement on the IBM CPU was approximately 5 minutes.

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[12] 'CPU' should in this context be understood as the unit enveloping the main circuitry, i.e. the computer itself.
[13] The CE (Conformité Européenne or European Conformity) mark indicates that the product conforms to the rules set out in the relevant European health, safety and environmental protection directives.

Paper ball: A ball of paper was used as the largest ignition source. This produced significantly greater ignition energy with approximately 10 cm (≈ 4 inch) flames. The duration of impingement of this ignition source was approximately 90 seconds. Two pieces of A4 white, unlined paper were used to create the ball.

## Test configuration

The hood outside of the ISO 9705 room was used for all tests. The products were weighed during the tests, and the mass loss rate (MLR) and heat release rate (HRR) were registered.

## Test results

It should be noted that the fire safety of European printers and computers is governed by IEC 60950, "Safety of information technology equipment, including electrical business equipment", which defines that the enclosure material should pass at least a HB classification. The fire safety of American information technology (IT) equipment is governed by the voluntary UL1950 standard, which is harmonised with IEC 60950, and also requires at least HB classified enclosure material.

Epson Inkjet Printer: The Epson printer had a nominal weight of 5 kg. All plastic material appears to have been combusted before the test was terminated. The total amount of combustible material has been estimated to be approximately 2.03 kg based on the mass loss data. The printer test was terminated 23 minutes after ignition.
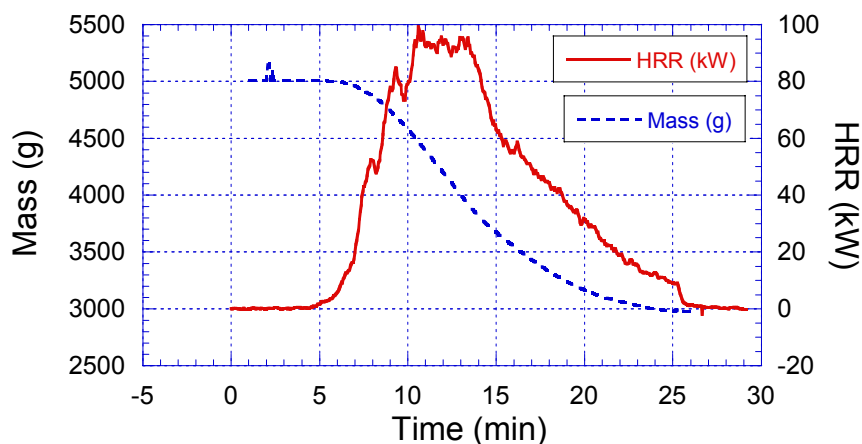


**Figure 86    Heat release rate and mass loss for Epson printer. The slight increase in weight at approximately 2 minutes occurs when the methanamine pill is ignited.**

Hewlett Packard (HP) CPU: The HP CPU had a nominal weight of approximately 8.8 kg. All plastic material at the front of the CPU (where ignition took place) was combusted before the CPU extinguished itself. The total amount of material combusted has been estimated to be 320 g based on the mass loss data
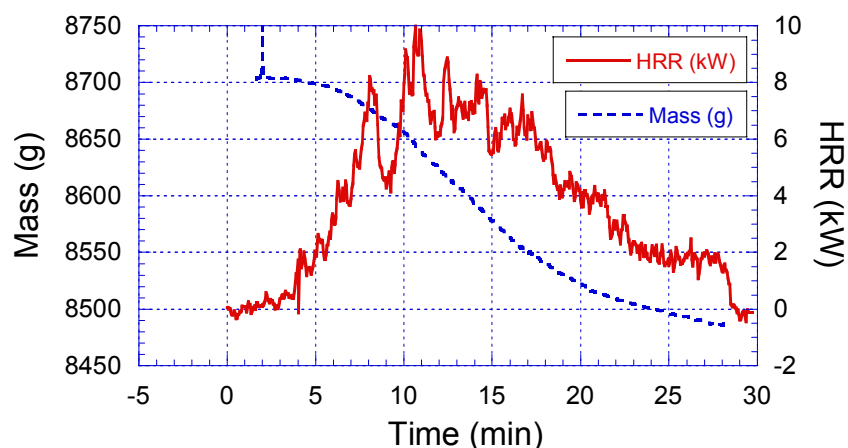
**Figure 87 Heat release rate and mass loss for HP CPU. The slight increase in weight at approximately 2 minutes occurs when the methanamine pill is ignited.**

IBM CPU: The IBM CPU had a nominal weight of approximately 14.6 kg. No ignition was seen using any of the three ignition sources tested.

## TV-set experiments

See [36] for the full report.

### Ignition sources

Match sized
The smallest ignition source used was an open ended tube (internal diameter: 5 mm) connected to butane. A flame the size of a match was lit on the end of the tube. This burner had a heat release that was too low to measure using the hood system in the ISO 9705 room [14] but it is estimated that the heat release rate was approximately 0.5 kW.

Small CBUF burner
A small square burner was used as the second ignition source. This burner was used in the CBUF project [37] for small scale furniture tests. It was connected to propane and run at a heat release rate of approximately 10 kW.

CBUF burner
The square burner developed in the CBUF project for full scale furniture testing was used as the third ignition source. It was connected to propane and run at a heat release rate of approximately 30 kW. This burner is physically identical to the burner described in Californian Technical Bulletin 133.

### Experimental descriptions

Both TVs were placed on a platform that was positioned on scales connected on line to give a measurement of the mass loss rate while the TV burned. The scales have a resolution of approximately 10 g and the TVs plus platform weighed just under 100 kg in both cases prior to start of the experiment.

**Fire Performance**

Table 8 below summarises the main fire performance parameters for the large scale experiments on the burning US and Swedish TVs. The ignition tests carried out on the US TV cannot be analysed meaningfully in this way and are included in a graphical comparison only.

**Table 8    Fire performance parameters for the large scale experiments. The experimental time starts at 0, although the ignition source is not in position before 2-5 minutes after this.**

| Parameter | Swedish TV | US TV |
|---|---|---|
| Time for average (min) | 5 - 50 | 2 - 23 |
| Ignition source application (min) | 5 | 2 |
| Ignition source power (kW) | 1 | 30 |
| Time to ignition (s)[*] | ~ 30 | ~ 90 |
| Peak HRR (kW) | 240 | 130 |
| Average HRR | 60 | 60 |

[*]Time after application of ignition source
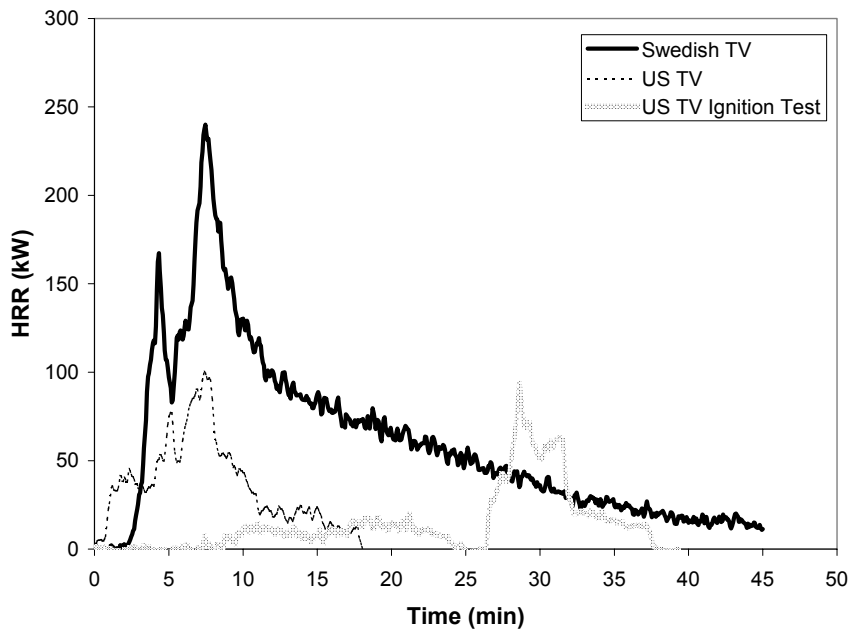


**Figure 88    Comparison of HRR for the three large scale experiments. The Swedish and US TV tests have been adjusted so that t=0 corresponds to the time of ignition. The HRR curve for the US TV has been corrected for the 30 kW ignition source.**

The mass as shown in Figure 89 indicates that most of the 6.5 kg of combustible material estimated to be present in the Swedish TV was burned while only approximately two thirds of the combustible material estimated to be present in the US TV was burned. This was despite the fact that a large ignition source was used to ignite and burn the US TV.
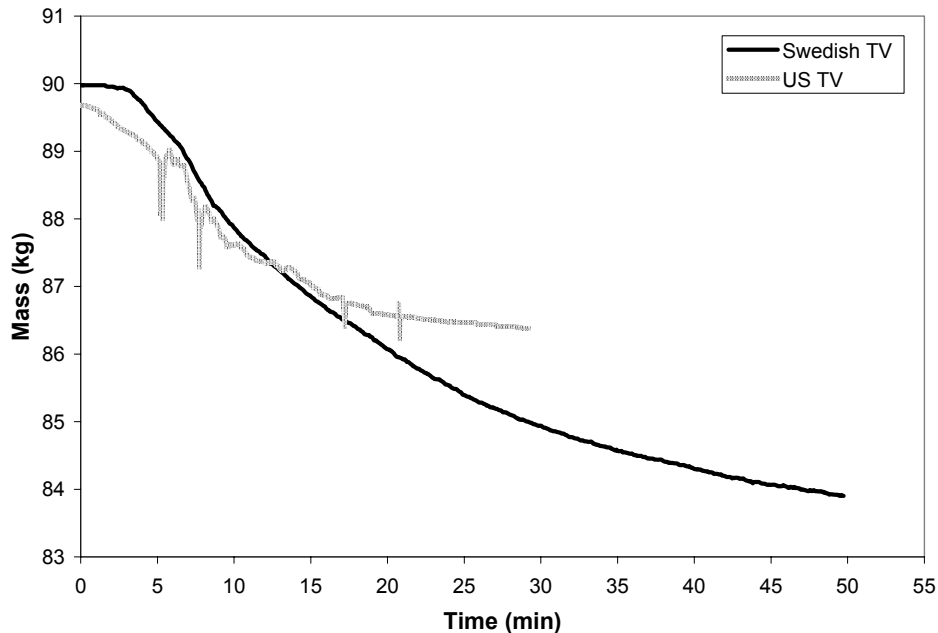


**Figure 89**   **Comparison of mass behaviour for the two large scale fire experiments. The total mass includes the TV, and a platform for the TV to stand on. The time scale has been adjusted to correspond to the time scale used in Figure 88.**

**Reference**

[33]  Simonson M., *Report for the fire testing of Computer monitors,* published on the web 2000: http://www.firemarshals.org/issues/home/computer_fires.html
[34]  Simonson M., *Report for the fire testing of Deskjet printers,* published on the web 2000: http://www.firemarshals.org/issues/home/computer_fires.html
[35]  Simonson M., *Report for the fire testing of one printer and two CPUs,* published on the web 2000: http://www.firemarshals.org/issues/home/computer_fires.html
[36]  Simonson M *et. al .*, *Fire-LCA Model: TV Case Study,* SP Report 2000:13
[37]  *Fire Safety of Upholstered Furniture –the final report on CBUF research programme.,* Editor B. Sundström, European Comission-Measurements and Testing,  Report EUR 16477 EN.

# Annex D   Train compartment material tests

Within the European group for standardisation (CEN/CENELEC), a project was initiated in 1997 with the aim of establishing fire testing proceedures for train wagon material. The project was named FIRESTARR [38]. The intention was to define tests that would capture material qualities such as its ignitability, flame spread behaviour, rate of heat release (HRR), rate of smoke production (SPR) and the amount of poisonous gases produced by the material during a fire.

## Surface lining products selected

The table below gives all the products selected for the small scale tests of surface lining materials.

**Table 9**

| CODE | PRODUCT | LOCATION |
|------|---------|----------|
| PS03 | Polyester GRP (good fire performance) | ceiling |
| PS04 | Sandwich plywood - decorative laminate | wall |
| PS05 | Polyester GRP (low fire performance) | wall |
| PS06 | Melamine formaldehyde phenol formaldehyde laminate | wall and ceiling |
| PS07 | Plywood (flame retardant) | wall and ceiling |
| PS08 | Plywood (flame retardant) | floor |
| PS09 | Plywood | wall and ceiling |
| PS10 | Plywood | floor |
| PS11 | Melamine formaldehyde resin | wall and ceiling |
| PS12 | Melamine formaldehyde resin laminate bonded Al | wall |
| PS13 | Phenolic - GRP painted | wall |
| PS14 | Sound insulation compound on steel plate | non reachable |
| PS15 | Insulation synthetic fibre (polyester) | wall and ceiling |
| PS16 | Glass wool | non reachable |
| PS17 | Phenolic foam | wall and ceiling |
| PS18 | Decorative laminate | wall and ceiling |
| PS19 | Film self adhesive | wall and ceiling |
| PS20 | Aluminium painted | wall and ceiling |
| PS21 | Wall carpet (polyester) | wall |
| PS22 | Ceiling carpet (polyester) | ceiling |
| PS23 | Polycarbonate | light diffusers |
| PS24 | Acrylic | light diffusers |
| PS25 | Polycarbonate (good fire performance) | frame of seat |
| PS26 | Polycarbonate (low fire performance) | frame of seat |
| PS27 | ABS | frame of seat |
| PS28 | PVC/aluminium sandwich | floor |
| PS29 | Rubber floor covering (high fire growth) | floor |
| PS30 | Wool nylon carpet | floor |
| PS31 | Polypropylene needle felt carpet | floor |
| PS32 | Polychloroprene rubber | seal, inside door |
| PS 33 | Profiled rubber (on aluminium profile) | front of luggage rack |

# Furniture products selected

The following table gives all the furniture products selected for the small scale tests.

**Table 10**

| CODE | PRODUCT | LOCATION |
|------|---------|----------|
| PF01 | Sunblind in glass and PVC | wall |
| PF02 | Curtains in PVC fibre | wall |
| PF03 | Curtains in preoxydate fibre | wall |
| PF04 | Curtains in polyester | wall |
| PF05a | Mattress foam | bedding |
| PF05b | Mattress covering | bedding |
| PF06 | Sheet | bedding |
| PF07 | Blanket | bedding |
| PF08a | Pillow (stuffing) | bedding |
| PF08b | Pillow (covering) | bedding |
| PF09 | Silicone unlacerable fabric | seat |
| PF10 | Polyurethane foam | seat |
| PF11 | Seat covering knitted velvet | seat |
| PF12 | Seat covering « en drap » | seat |
| PF13 | Seat covering in simulated leather | seat |
| PF14 | Seat interlayer polyacrylate-aramide fibre | seat |
| PF15 | Polyurethane foam | seat |
| PF16 | Seat covering wool / synthetic fibre | seat |
| PF17 | Seat covering synthetic fibre | seat |
| PF18 | Seat covering wool / acrylic fibre | seat |
| PF19 | Seat covering texoïd | seat |
| PF20 | Seat interlayer polyacrylate-aramide fibre | seat |
| PF21 | Polyurethane foam | seat |
| PF22 | Seat covering polyester fibre | seat |
| PF23 | Seat covering wool / polyester fibre | seat |
| PF24 | Seat interlayer skin polyester | seat |
| PF25 | Integral skin polyurethane foam | seat |
| PF26 | Polyurethane foam | seat |
| PF27 | Seat covering woollen spun cloth | seat |
| PF28 | Seat covering double plush seating moquette, untreated | seat |
| PF29 | Seat covering double plush seating moquette, Zirpro treated | seat |
| PF30 | Seat covering cut and uncut seating moquette, untreated | seat |
| PF31 | Seat interlayer fibrous glass substrate with polymeric treatment and special coating | seat |
| PF32 | Seat interlayer polyacrylate-aramide fibre | seat |

For seats, which are probably the part of vehicles most frequently involved in fires, it was decided to test different combinations from 4 countries. The table below gives the combination selected.

**Table 11**

|      | Foam | Interlayer | covering |
|------|------|------------|----------|
| C01  | PF10 | PF14 | PF11 |
| C02  | PF10 | PF14 | PF12 |
| C03  | PF10 | PF14 | PF13 |
| C04  | PF15 | PF20 | PF16 |
| C05  | PF15 | PF20 | PF17 |
| C06  | PF15 | PF20 | PF18 |
| C07  | PF15 | PF20 | PF19 |
| C08  | PF21 | - | PF22 |
| C09  | PF21 | - | PF23 |
| C10  | PF26 | PF32 | PF27 |
| C11  | PF26 | PF32 | PF29 |
| C12  | PF26 | PF32 | PF30 |
| C13  | PF26 | PF31 | PF28 |
| PF09 | Silicone unlacerable fabric | | |
| PF25 | Integral skin polyurethane foam | | |

## Tests Selected

The main objective was to select small and large-scale test methods which would relate to the fire scenario 'arson on a seat in a passenger compartment'. Tests were selected so that fire conditions were appropriate to the initial stage, early developing stage and developing stage (pre-flashover) within a small compartment.
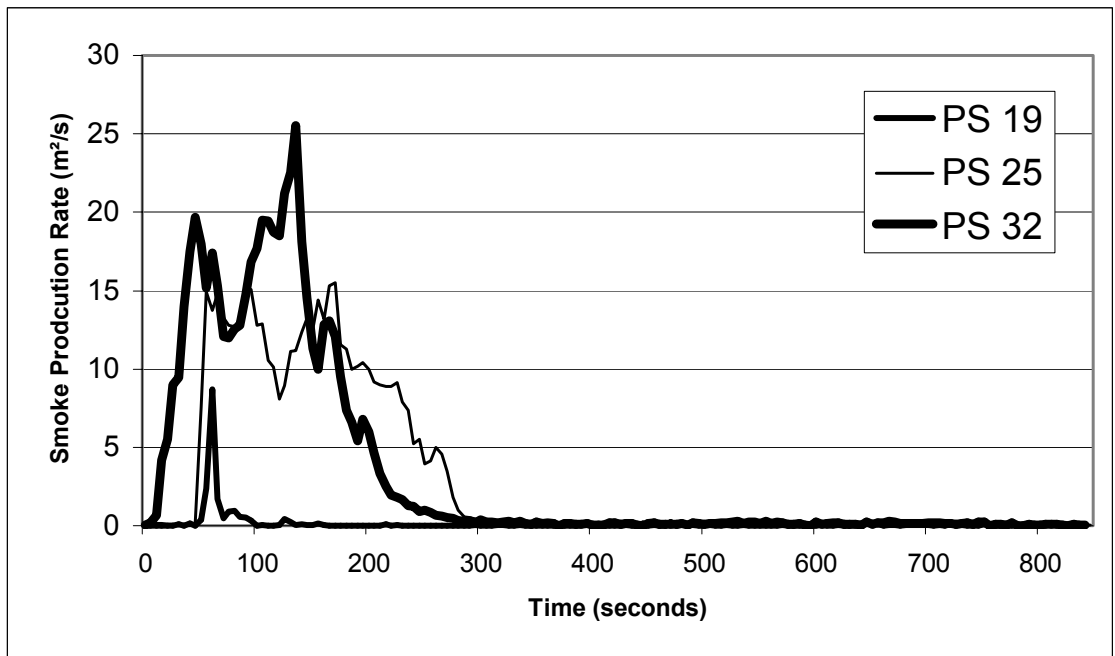
## Small-Scale Tests

A number of different small scale tests were used during the FIRESTARR project [38] and one of those were the ISO 5660 [12] Cone Calorimeter test.

Important measures of material quality obtained during such a test is the HRR together with the SPR (Smoke Production Rate). Example of such results from test on different surface lining material used in train compartments are shown in Figure 90 and Figure 91.
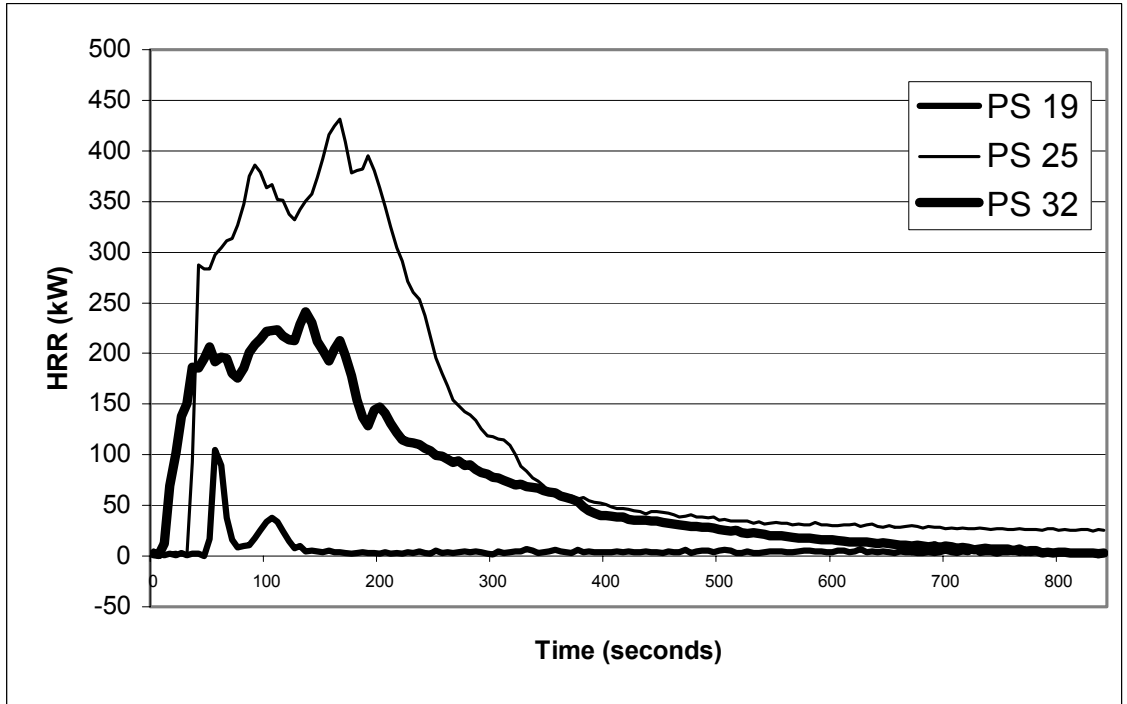
**Figure 90    Typical HRR results from Small-Scale ISO 5660-2 Tests (50kW/m²).**



**Figure 91    Typical Smoke Production Rate results from Small-Scale ISO 5660-2
              Tests (50 kW/m²).**

## Large scale furniture test

The large scale test method for furniture products was selected for seats that are the main furniture products found in a railway carriage.

The test method to be carried out in large scale test for a furniture product was the NT FIRE 032 (furniture calorimeter [39]). The ignition source consisted of a square burner which simulated the same thermal attack on a seat as that given by a 100 g burning paper cushion.

To improve the seats and their behaviour regarding possibility of vandalism, three vandalised levels were defined to test the seats :

- vandalised level 0 : not vandalised at all ;
- vandalised level 1 : a cut (cross shape) on the back and on the seat ;
- vandalised level 2 : vandalised level 1 and the fabric (cover and interliner) pulled away from the foam.

The ventilation conditions essentially represented a well-ventilated railway compartment with door open. Examples of results from large scale furniture tests are shown in figure 92.
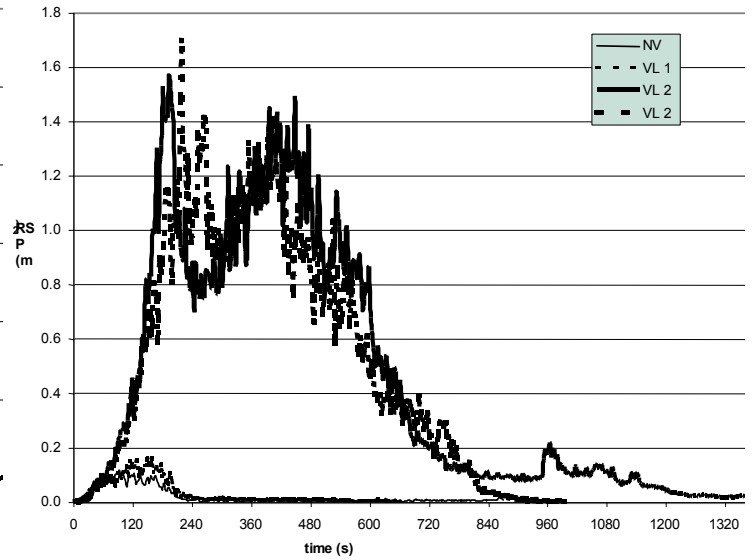
## Real scale test

A small compartment was reproduced in the laboratory. The compartment may be assumed to have a volume of approximately 9 m$^3$. The ventilation conditions in the compartment essentially represented a real ventilated railway compartment with door firstly closed for 3 minutes and then opened. The compartment was sited underneath the standard ISO 9705 [14] hood/duct system. During all the tests, the flow rate in the exhaust duct system was fixed at 3,5 m$^3$/s.  Two seats were placed edge to edge inside the compartment and positioned on the right wall in the corner next to the window. Examples of real scale experiments are shown in Figure 93 and Figure 94.
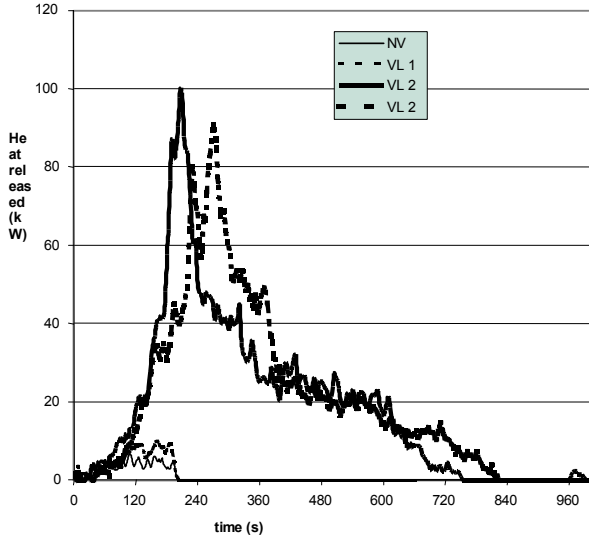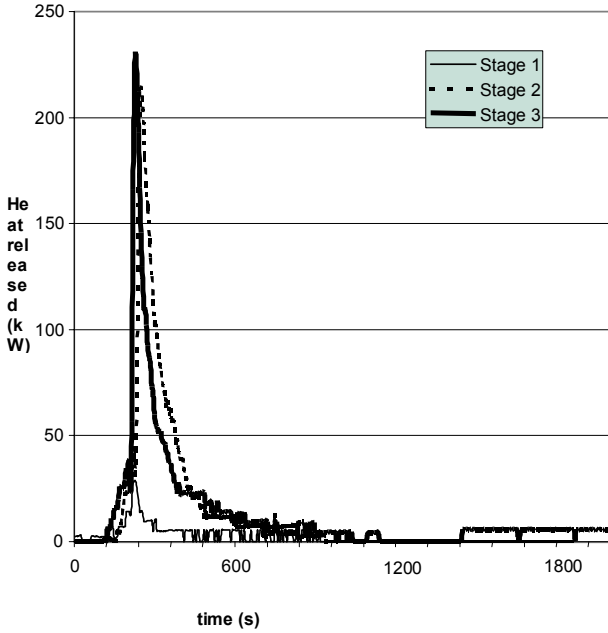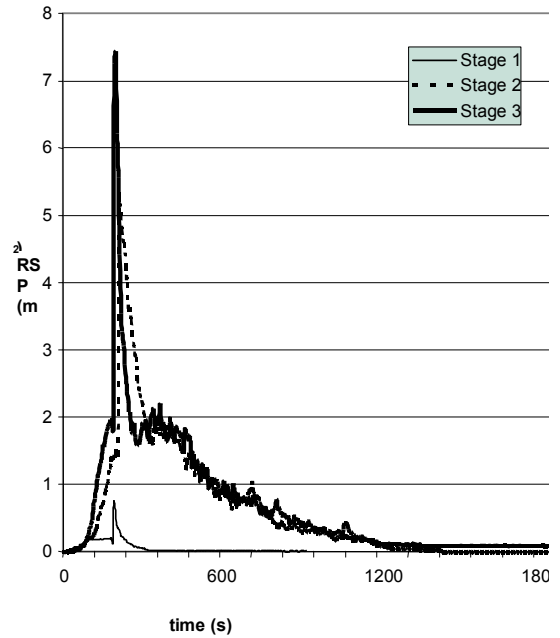
**Figure 92    Examples of Vector data for Large and Real scale tests results on railway seats.**
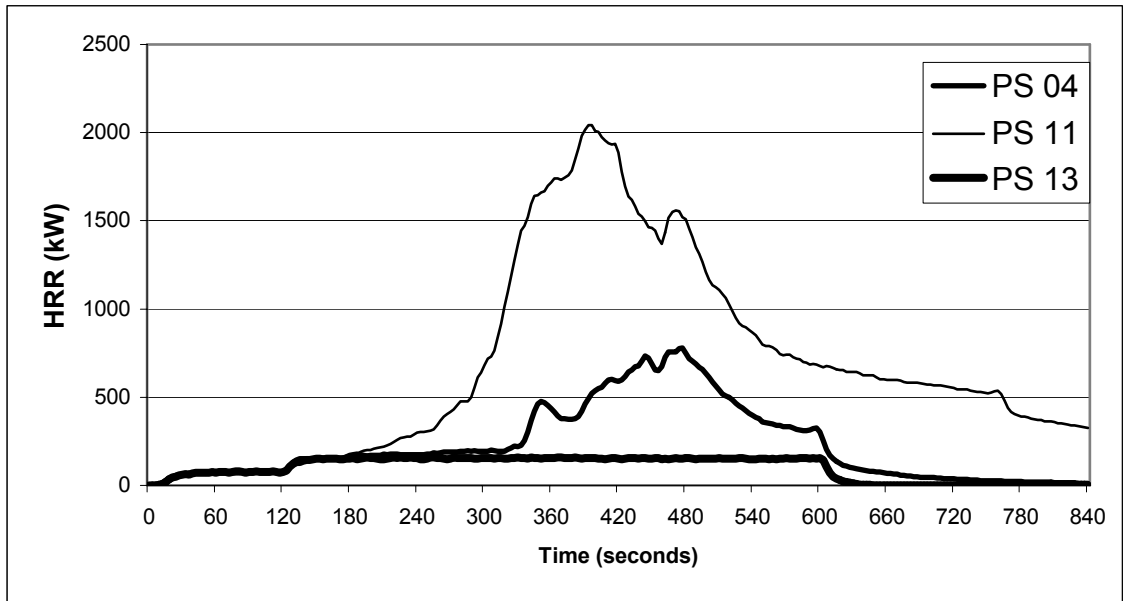
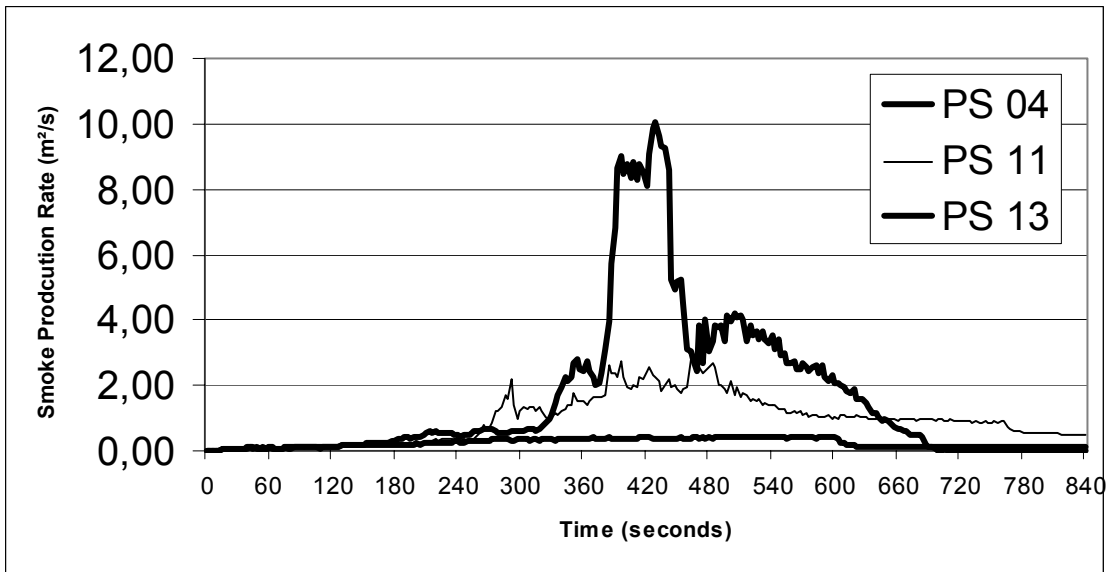**Figure 93    Typical HRR results from Real-Scale Train Compartment Tests.**



**Figure 94    Typical Smoke Production Rate results from Real-Scale Train Compartment Tests.**

# References

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