# AN OVERVIEW OF THE REAL SCALE TESTS IN THE FIPEC PROJECT (FIRE PERFORMANCE OF ELECTRICAL CABLES)

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## ABSTRACT

The FIPEC project is a research project funded by DG XII of the European Commission and co-financed by a large number of European cable manufacturers, cable material manufacturers, cable users and governmental research bodies. The FIPEC project has different levels of testing ranging from small scale to real scale. This article will discuss the real scale tests performed in the project. It explains the strategy behind the tests and gives an overview of the tests performed. The tests performed form a unique comparison of a number of horizontal and vertical test set-ups involving cables. Parameters such as heat sources, configuration, ventilation and loading were studied. In all tests the measurements were not limited to flame spread but heat release and smoke and toxic gas measurements were also taken. The outcome of this work was two set-ups, one horizontal and one vertical, which were used for the data base tests within the project.

## INTRODUCTION

The FIPEC project [1,2,3] has the following objectives:

- Develop or modify fire test methods for electrical cables offering improvements on existing IEC test methods
- Develop or adapt the cone calorimeter test to use it for small scale testing of electrical cables.
- Develop a correlation model for the prediction of fire performance of electrical cables based on the results of small scale tests.
- Develop bases for a calculation model for the prediction of realistic fire performance of electrical cables, in some key constructions, based on the results of small scale tests on materials.
- Investigate the validity of models comparing the output from models with realistic design fire test data.

The main core in this project is the performance of a number of real scale tests. The strategy and some of the results of these tests will be discussed in this paper.

## TESTING APPROACH

The WP 1 review in the FIPEC project determined the major scenarios for study to be Power plants, Vehicles (trains, ships and aircraft), Tunnels and Occupancies (e.g. underfloor voids, ceiling voids and riser shafts). Each scenario revealed specific characteristics that relate to configuration, type and amount of cable used.

Within the FIPEC project, work package 1 investigated the main cable installation practices in Europe such as type of cable trays, type of cables, construction of cables, cable materials, loading levels and types of fixing, etc. In order to conduct the real-scale fire test it became clear that a number of steps had to be performed which will be explained in the following paragraphs.

A number of scenarios were selected in WP 1. These included cable installations that were both vertically and horizontally orientated. A number of test configurations were selected which represent the scenarios envisaged. However each configuration cannot be used for all the cables and hence a selection of the most appropriate test configurations, for the real scale database within FIPEC, was necessary. This database will be used for the development of a full-scale test, development of a small-scale cable and material test and for modelling. A schematic overview of these different steps in the real scale test programme is given in figure 1 This article will only discuss the results of the first three steps. The data base tests will be reported later.

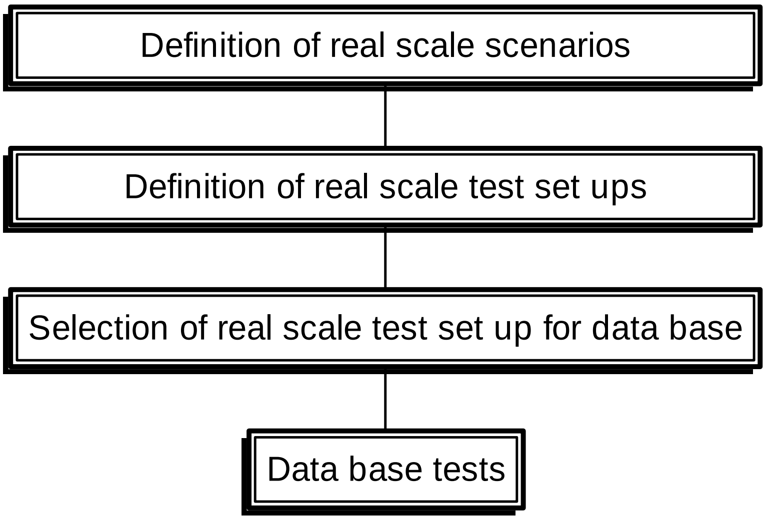


*Figure 1 Overview of the different steps in the real scale test programme*

## OVERVIEW OF MAIN REAL SCALE TEST CONFIGURATIONS

From the information given in the report of WP 1, a set of real scale test configurations can be identified which cover the scenarios mentioned above. First they can be divided into horizontal and vertical configurations. A further division is made based on whether or not there is thermal feedback from an adjacent surface (wall, floor, and ceiling). Hence three subdivisions can be made, namely open, semi-closed and closed. The closed configuration may be tested with or without ventilation. Finally it is necessary to investigate the void configuration i.e. a set up where the cables are mounted inside a wall with very limited air access. This type of configuration is very specific and investigation of these scenarios may be limited, though it should be included.

Figures 2 to 4 illustrate the selected test configurations. Table 1 shows how the real scale test configurations relate to the four key scenarios identified in WP1 of the FIPEC project.

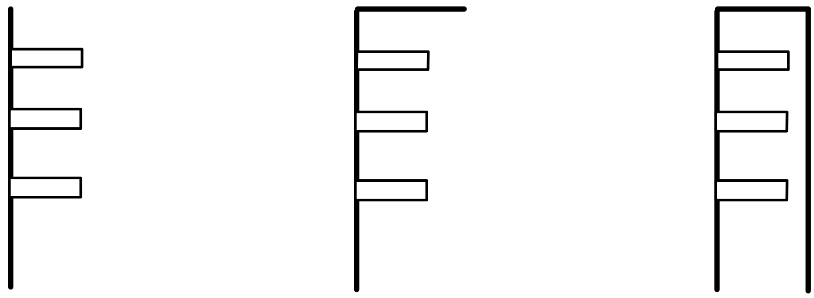

*Figure 2 Overview of horizontal test configurations (side view)*

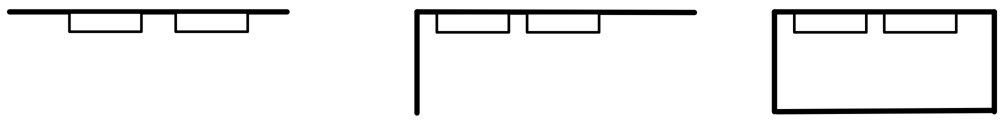

*Figure 3 Overview of vertical test configurations (top view)*

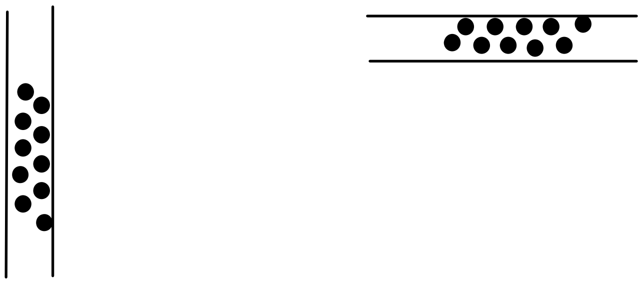

*Figure 4 Overview of the ”void” test configuration (side and top view)*

**Table 1 Overview of connection test configurations-scenarios**

| | Open | Semi-closed | Closed | Closed with ventilation | Void |
|---|---|---|---|---|---|
| Horizontal | Power plant<br>Vehicles<br>Tunnels<br>Occupancies | Power plant<br>Tunnels | Power plant<br>Vehicles<br>Tunnels<br>Occupancies | Tunnels<br>Occupancies | Vehicles<br>Occupancies |
| Vertical | Power plant<br>Occupancies<br>Tunnels | Power plant | Power plant<br>Tunnels<br>Occupancies | Tunnels<br>Occupancies | Vehicles<br>Occupancies |

## COMPARISON OF MAIN TEST CONFIGURATIONS

During this test series the following orientations and configurations were tested. A rationale behind, and description of, the different configurations is given above.

- Open horizontal configuration
- Semi-closed horizontal configuration
- Closed horizontal configuration with one side wall partially closed
- Closed horizontal configuration without side walls (with and without ventilation)
- Open vertical configuration
- Semi-closed vertical configuration
- Closed vertical configuration (with and without ventilation)
- Vertical Void configuration
- Horizontal void configuration

Three different tests were used in the open configuration to tune the heat source programme. The following heat source programmes were used:

- Heat source programme 1
  - 10 minutes at 20 kW
  - 10 minutes at 40 kW
  - 10 minutes at 100 kW
  - 10 minutes at 200 kW
- Heat source programme 2
  - 10 minutes at 100 kW
  - 10 minutes at 300 kW
- Heat source programme 3
  - 5 minutes at 40 kW
  - 10 minutes at 100 kW
  - 10 minutes at 300 kW

If flame spread, or sufficient heat release, was observed during a certain burner heat release level the heat release level was not increased to the next level. If the complete cable tray was burning the test was stopped by extinguishment.

Four different cables were used for these tests with the following characteristics, code and loading:

- Cable A
  95 mm$^2$ unarmoured
  6 cables per tray with a distance of 2 cm between each cable
- Cable B
  95 mm$^2$ armoured
  6 cables per tray with a distance of 2 cm between each cable
- Cable C
  7×1.5 mm$^2$ unarmoured
  10 cables per tray with a distance of 2 cm between each cable
- Cable D
  27×2×0.5 mm$^2$ unarmoured
  7 cables per tray with a distance of 2 cm between each cable

All the cables used have had their fire performance enhanced by the addition of flame retardants and fillers. Not all cables could be tested in all combinations but the actual tests performed are shown in table 2. The voids were constructed as closed cable trays, i.e. with steel locks.

**Table 2** Overview Of Tests Performed

| Test number. | Heat source number | Orientation | Configuration | Ventilation | Trays | Cables |
|---|---|---|---|---|---|---|
| 1 | 1 | Horizontal | open | Natural | 3 | A |
| 2 | 2 | Horizontal | open | Natural | 3 | A |
| 3 | 3 | Horizontal | open | Natural | 3 | A |
| 4, 5, 6 | 3 | Horizontal | semi closed | Natural | 3 | A, C, D |
| 7 | 3 | Horizontal side wall closed | closed | Natural | 3 | A |
| 8, 9, 10, 11 | 3 | Horizontal no side walls | closed | Natural | 3 | A, B, C, D |
| 12 | 3 | Horizontal no side walls | closed | Forced 0.8 m/s | 3 | B |
| 13 | 3 | Vertical | open | Natural | 2 | B |
| 14, 15, 16, 17 | 3 | Vertical | semi closed | Natural | 1 | A, B, C, D |
| 18 | 3 | Vertical | closed | Natural | 1 | B |
| 19, 20 | 3 | Vertical | closed | Forced 0.6m/s and 1 m/s | 1 | B |
| 21 | 20 kW IEC burner | Void horizontal | closed | Natural | 1. | C |
| 22 | 20 kW IEC burner | Void vertical | closed | Natural | not appr. | C |

**RESULTS AND DISCUSSION OF HORIZONTAL SCENARIOS**

### Comparison of the heat source programme in 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 5. It can be seen that a 20 kW heat source causes little effect, and that 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. However, 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 the other tests, in order to observe at which heat source levels flame spread would occur. The strategies explained above (relating to the increase to the next heat release level and the specimen extinguishment) were applied for all remaining tests. Hence some tests were stopped before the end time.

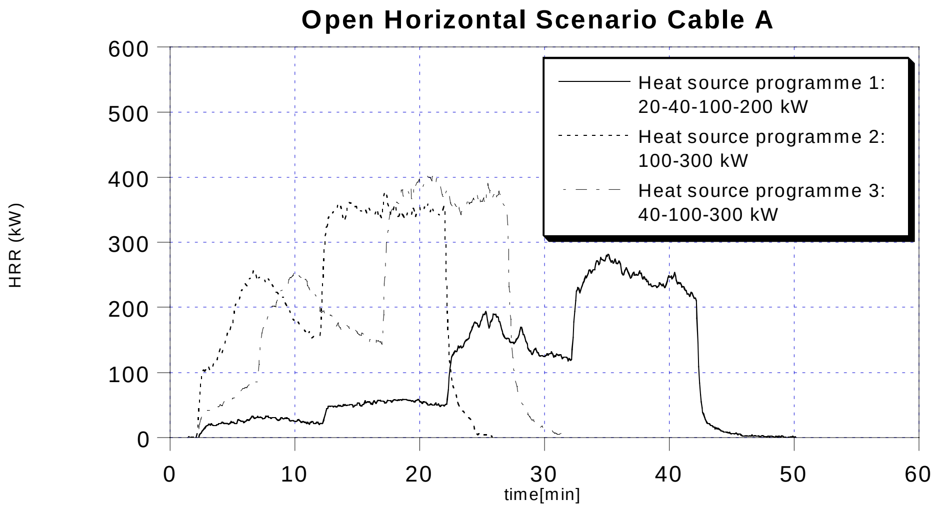


*Figure 5 Comparison of different heat source in the open horizontal scenario*

**Comparison of different horizontal configurations without ventilation**

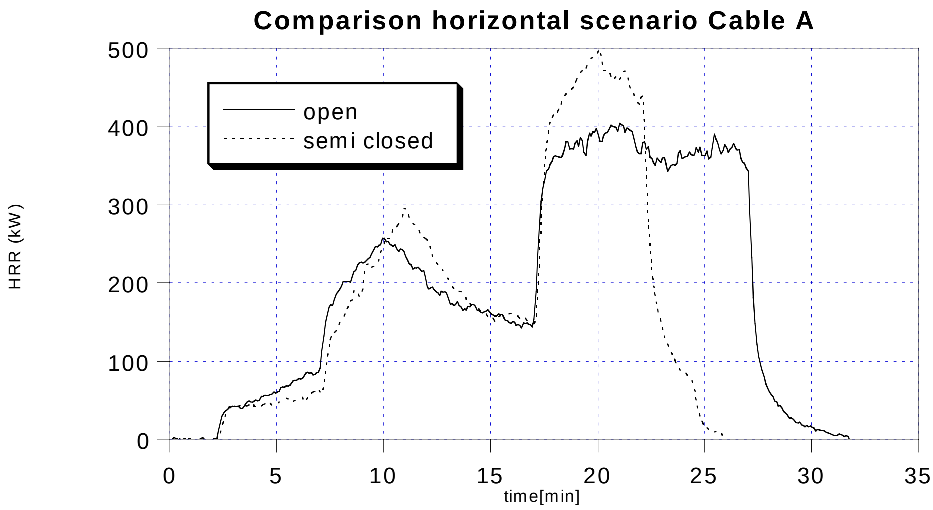


*Figure 6 Comparison of open and semi closed horizontal scenarios for cable A*

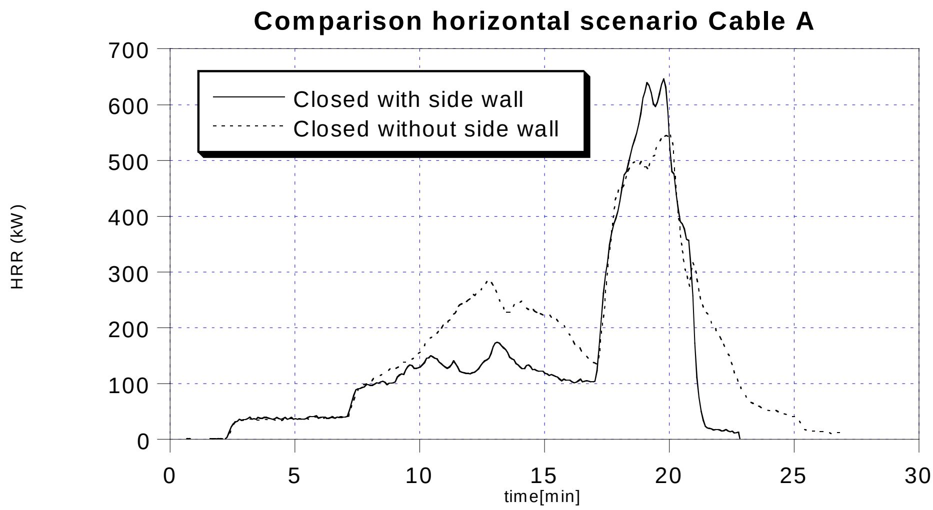


*Figure 7 Comparison of closed horizontal scenarios for cable A*

It is clear from Figure 6 that the semi closed configuration generates more heat release than the open configuration. Furthermore, it can be seen in Figure 7 that the closed configuration shows clear evidence of flame spread for Cable A at the 300 kW input level (i.e. at 15 minutes). The vertical side wall causes initiation of the flame spread to be delayed. 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.

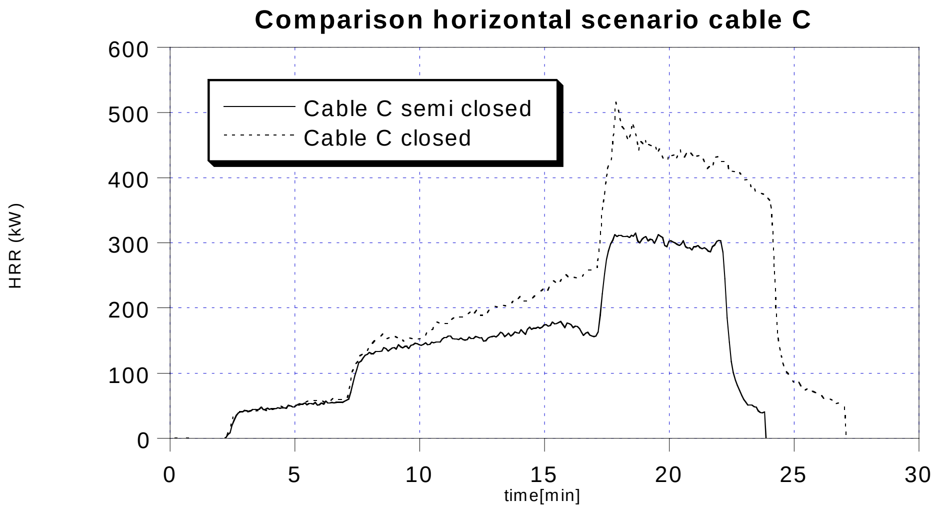


*Figure 8 Comparison of horizontal scenarios for cable C*

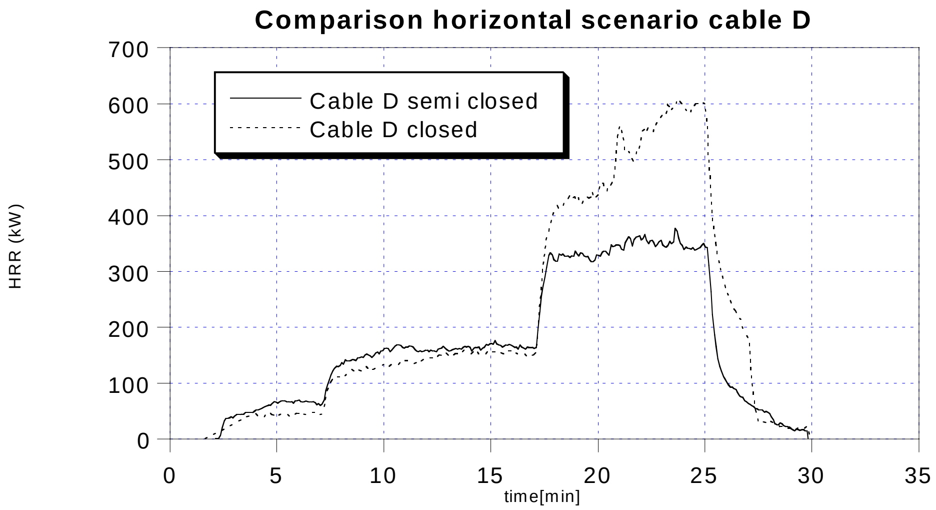


*Figure 9 Comparison of horizontal scenarios for cable D*

Test results on Cables C and D, in Figure 8 and Figure 9, show similar trends. 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 different horizontal configurations with ventilation**

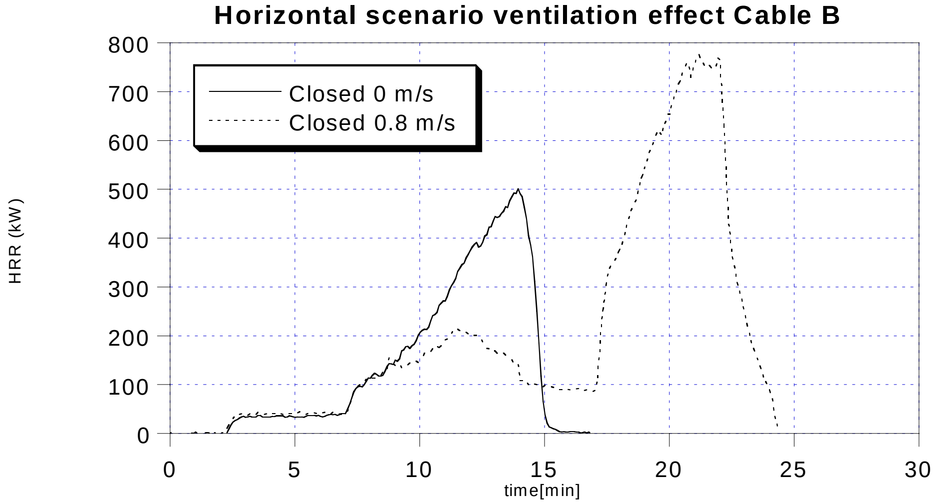


*Figure 10 Comparison of closed horizontal scenarios for cable B*

The effect of forced ventilation in the closed horizontal scenario was investigated with Cable B. It is clear from Figure 10 that increased ventilation results in increasing flame spread, but only at the 300 kW level. At the 100 kW level the non-ventilated test is a lot more severe. Note also that the test with no forced ventilation (0 m/s) was stopped after 15 minutes, while the test with forced ventilation (0.8 m/s) was also stopped before the end, after the fire was extinguished.

**Comparison of cables in the different horizontal configurations**

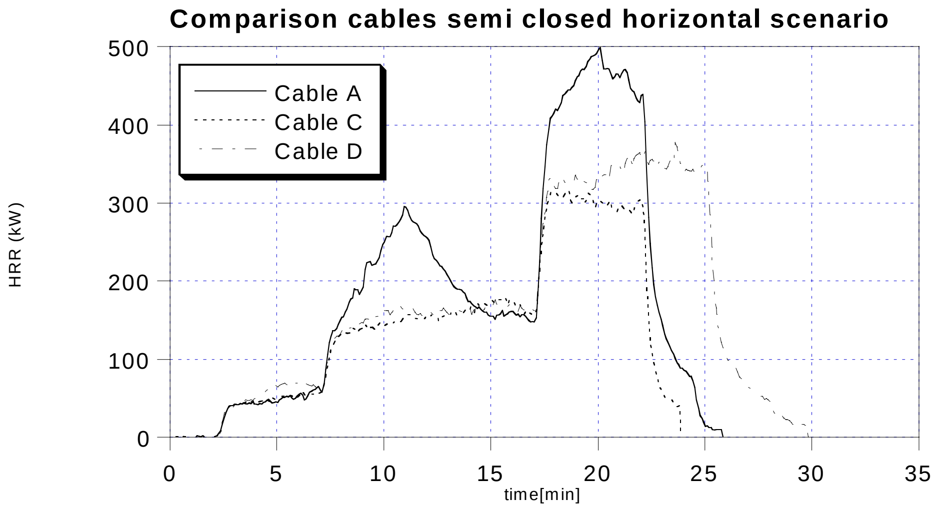


*Figure 11 Comparison of cables in the semi closed horizontal scenario*

Test results for three different cables, in the semi closed horizontal scenario, are shown in Figure 11. Cables C and D generate very similar results, and out-perform cable A, which spreads flame significantly faster. This scenario is likely to be inadequate for distinguishing the fire performance of cables.

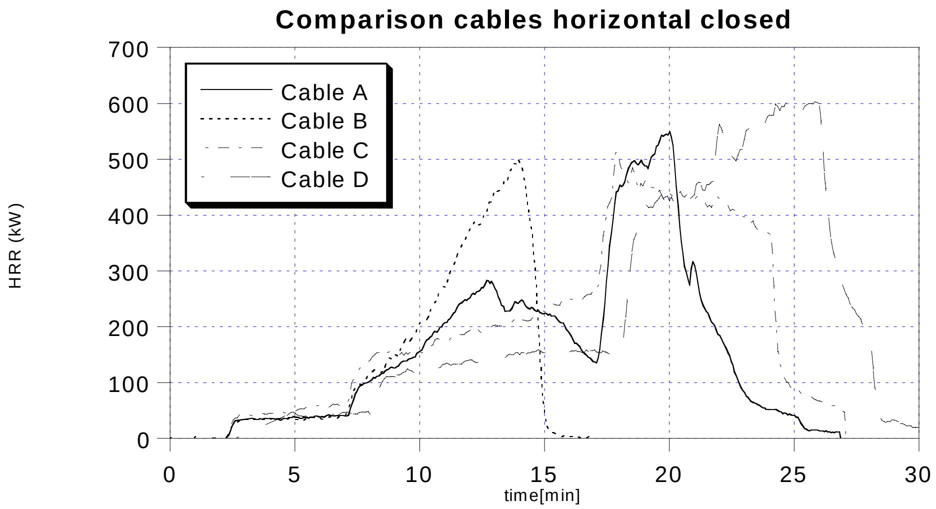


*Figure 12 Comparison of cables in the closed horizontal scenario*

The test results for all four cables in the closed horizontal scenario are shown in Figure 12. Clearly, the flame spread from Cable B is the fastest, followed by Cable A. Cables C and D perform similarly to one another at the 100 kW, 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.

## VERTICAL SCENARIOS

### Comparison of different vertical configurations without ventilation

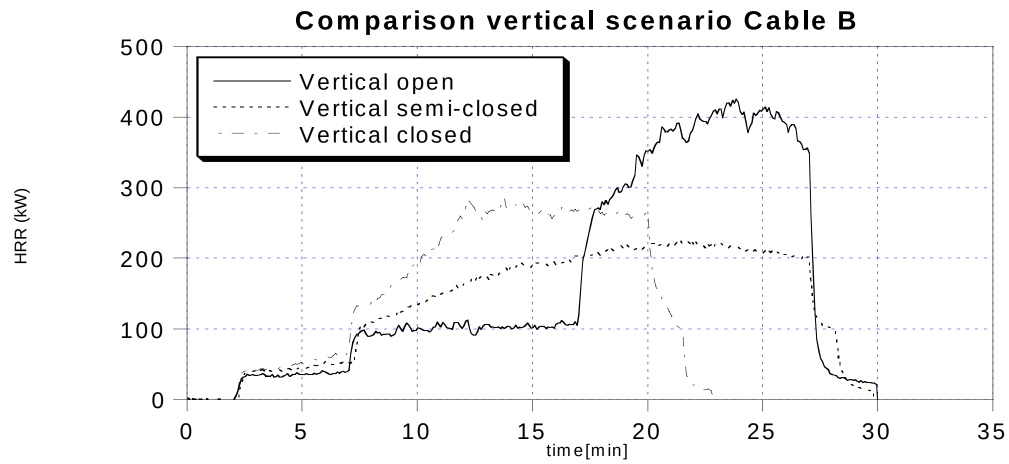


*Figure 13 Comparison of vertical scenarios for cable B*

Three vertical scenarios were investigated with one of the cables, Cable B, and the results are shown in Figure 13. The cable chosen was the one with the poorest fire performance in the closed horizontal scenario (see Figure 12). It can be seen that no flame spread occurs in this vertical scenario, unless there is, at least, a corner situation. It should be noted that the heat source was only increased to 300 kW in the open vertical situation. In fact, in the semi closed vertical situation (corner situation), and in the vertical closed situation, flame spread was observed at the 100 kW level, and further heat input was not necessary. It is interesting to observe that: (a) the heat released levelled out in the closed configuration once the whole tray was burning and (b) the fire is ventilation-controlled due to the closed set up. In the first test (open configuration) two parallel cable trays were mounted, but no lateral flame spread was observed. Hence it was decided to use only one vertical cable tray for all remaining tests to avoid excessive use of cables.

**Comparison of cables in the vertical closed configuration with ventilation**

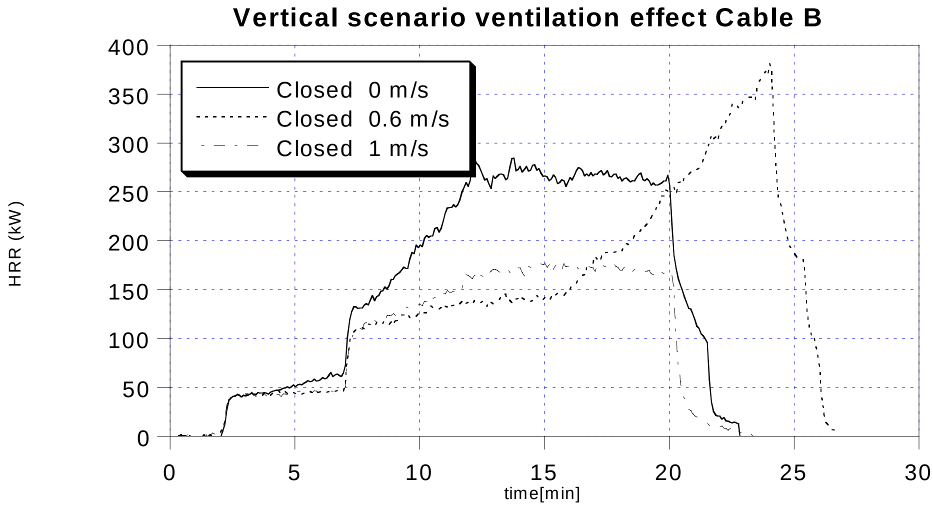


*Figure 14 Comparison of vertical closed scenarios with ventilation for cable B*

The effect of forced ventilation was studied in the vertical closed scenario with Cable B, and the results are shown in Figure 14. It can be observed that increasing the ventilation to higher airflow rates does not have large effects on flame spread in this set up. This can mainly be explained by the fact that the area where the cables have not yet ignited is cooled by the increased air flow and that the smoke gases are also cooled by the larger amount of incoming air. In fact, installation of cables in forced ventilation shafts is rare in Europe; thus, no more studies will be performed in this project with respect to ventilation. A complete study of the effect of ventilation would be very extensive and is not the main goal of this project.

**Comparison of cables in the different vertical configurations**

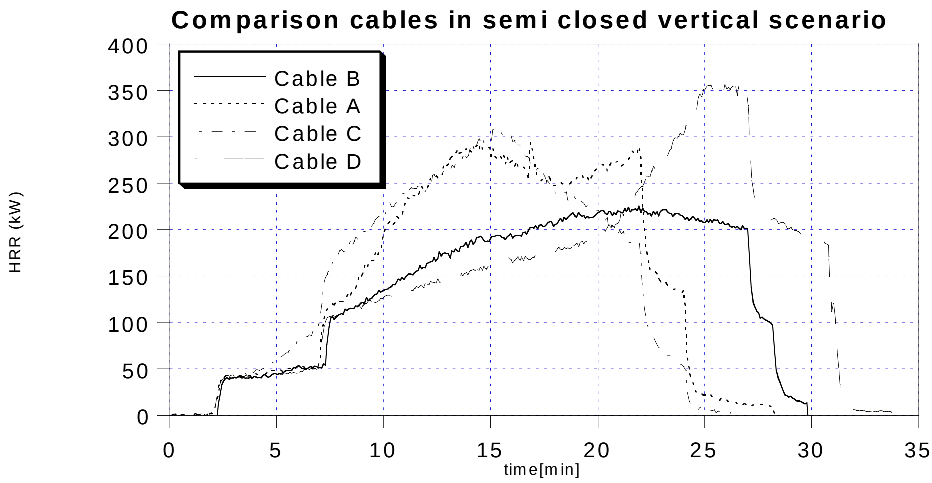


*Figure 15 Comparison of cables in the semi closed vertical scenariio*

Tests with all four cables in the semi closed vertical configuration are shown in Figure 15. It is clear that the behaviour of the various cables differs. Cables A and C spread flames first, followed by Cable B and finally by Cable D. All four cables showed a clear flame spread at the 100 kW heat input level, which means that this scenario is more severe than the horizontal scenario. It can also be seen that the semi closed or corner configuration is already capable of distinguishing between the fire performances of the different cables.

## RESULTS AND DISCUSSION OF 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 test produces a continuous flame spread on cable C. which can be considered as a high performance cable. Although only two 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. Although it was not foreseen in the project, it is suggested to run a limited number of cables in a vertical void scenario. The results of the vertical void scenario are given in Figure 16. The length of the cable was limited to 1 m, but even at such a short length a HRR of 100 kW is already observed. The results of the horizontal void scenario are not given since no real heat release contribution from the cable was observed.

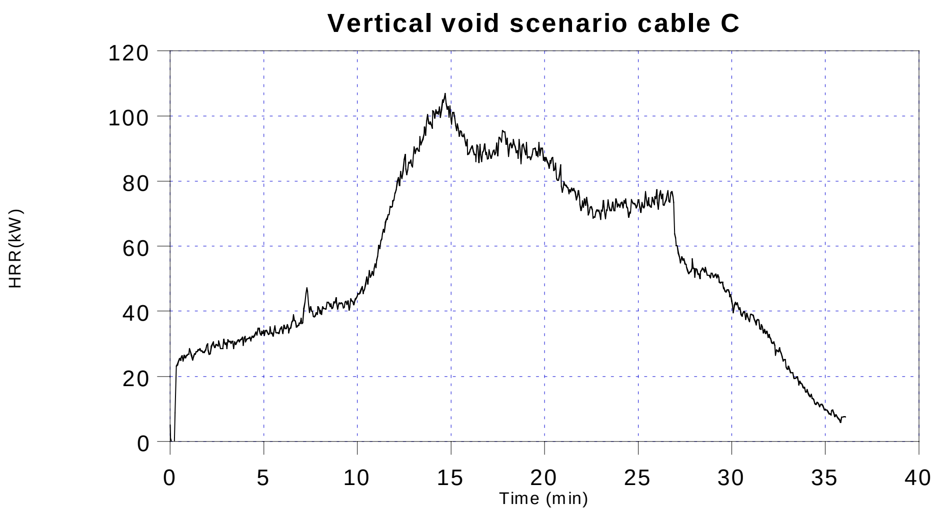


*Figure 16 Vertical void scenario*

## CONCLUSIONS: CHOICE OF TEST CONFIGURATIONS AND STATUS OF PROJECT

### Horizontal test configuration

Considering all the results and discussions reported above, the most efficient horizontal test set up was chosen to be:

- Closed horizontal configuration with no side walls
- No ventilation
- Heat source programme 3 (40-100-300 kW)
- Three cable trays installed with mounting of cables with half a cable diameter distance between the cables but with a maximum of 2 cm

The closed scenario, with no forced ventilation, is necessary in order to distinguish between the cables in the database. Cable mounting in highly ventilated areas is uncommon in Europe; thus, a non-ventilated scenario was chosen. A stepwise heat source programme will allow distinctions to be made between different cable groups that may appear similar at a single heat source level. Horizontal scenarios are less severe than vertical ones (both the literature and the tests performed show that), therefore only a limited number of cables in the database were tested horizontally.

**Vertical test set up**

Considering all the results and discussions reported above, the most efficient vertical test set up was chosen to be:

- Semi closed vertical configuration (corner situation)
- No ventilation
- Heat source programme 3 (40-100-300 kW)
- One cable tray installed with mounting of cables with half a cable diameter distance between the cables but with a maximum of 2 cm

The semi closed, non-ventilated scenario has been chosen here, since this scenario can already distinguish between the cables in the database. A completely closed vertical scenario could limit both the observations and the use of fully ventilated conditions. The purpose of these real scale tests is also to investigate the real scale fire behaviour of cables; hence it is advisable to avoid very under-ventilated conditions. A well ventilated set up will permit the use of the data as input to smoke and fire spread models, of both the zone and field type, which can address the under ventilated situation. A non-ventilated scenario was chosen, since most cables are not mounted in highly ventilated areas. A stepwise heat source programme will allow distinctions to be made between different cable groups that may appear similar at a single heat source level. The vertical scenario is considered more severe than the horizontal and the majority of the cables selected for the project were tested in this scenario.

**Status of project**

In total 46 data base tests were conducted. 10 of the selected cables were tested in the horizontal configuration and 36 were tested in the vertical configuration. During all these tests additional FTIR measurements have been performed. Currently, the large amount of data is being processed and evaluated.
A large scale test procedure based on IEC 60332-3 has been developed using HRR and SPR (smoke production rate) measurements
A cone calorimeter test procedure is developed for cables and materials.

## ACKNOWLEDGEMENT

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