INFLUENCE OF FIRES ON - AIR VELOCITY MEASUREMENTS AT DOWNSTREAM MEASUREMENT LOCATIONS

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ABSTRACT

Ventilation control in case of a fire is a very important issue in tunnel safety. In general an automatic system is employed in order to control smoke movement inside the tunnel. The major control parameter is the air velocity upstream the fire location. Depending on the ventilation philosophy critical or low air velocity philosophy might be applied. In both cases a proper measurement of the air speed is required. The control itself is performed by a PID or PID like controller, which triggers fan operations and uses the measured value of the air or smoke speed as feedback value.

The best solution would be having a measurement of the upstream situation, i.e. far away from any influence of the fire. However, there exist always locations inside the tunnel, for which this ideal conditions are not possible.

This paper deals with situations, where velocity information has to be taken from monitoring locations downstream the fire. Numerical simulations for wind distributions in a cross section for different heat release rates are performed and compared to measurements. The numerical simulations are performed with the FDS code.

Keywords: ventilation control system, fire in tunnels, sensor location in tunnels, air velocity

1. INTRODUCTION

Any incident with a fire inside the tunnel bears a quite big risk to tunnel users. In order to enhance rescue in such cases a controlled ventilation of the smoke is imperative in order to reduce human and capital losses.

There are multiple philosophies how to vent a tunnel during fire cases. Mainly a ventilation procedure for ‘critical velocity’ or ‘low velocity’ is applied. Both methods have their pros and cons [1]. In order to enable controlled incident/fire ventilation closed loop control systems are nowadays employed. The feedback information for such systems is the air/smoke velocity, measured by appropriate sensors at appropriate locations. This measurement shall represent the average air flow over the tunnel cross section.

Best practice is to measure the air velocity upstream of the fire. At such locations any influence from heat releases due to the fire can be avoided – as long as any backlayer of smoke does not reach the measurement location. However, as an incident can happen everywhere inside the tunnel, there might be the possibility that upstream air velocity sensors do not exist or are out of order. In such cases information of sensors downstream the fire have to be used. Of course in such situation each designer of a control system would promote the usage of a location as far as possible downstream, in order to have already a uniform flow situation.

Here the problem arises as any heat release in a vertical temperature gradient and hence in different velocities at different heights. Due to buoyancy forces generated by the fire the nearfield of the fire is highly turbulent with high temperatures at ceiling and low temperatures at ground level. Dependent on the heat release rate (HRR) the air flow at low levels could even be from both sides of the fire. The situation downstream of the fire is strongly influenced by the heat transfer to the walls (cooling down) and by turbulent mixing of air masses with different temperatures over the cross-section. The more turbulence is present, the more uniform the vertical temperature distribution will be. In tunnels with active jet fans downstream the fire the temperature profile will be much more uniform compared to natural flows.

This means that any point- or line measurement at a certain height downstream the fire gives only information about the velocity at that location. The interpretation of such a value for ventilation control purposes – where the upstream information is needed – is quite questionable.

2. EXPERIMENTAL DATA

According to the Austrian standard for ventilation design [3] a fire test has to be part of the commissioning test of a tunnel. During this test the performance of the ventilation system has to be checked by having two pool fires with a HRR of roughly 3 MW as source. According to the RVS 09.02.31 [3] a low velocity philosophy for ventilation in incident cases has to be applied.

During the course of the commissioning tests of the Niklasdorf tunnel in winter 2013/14 various tests were performed. During one test air velocity was recorded at different locations inside the tunnel. Fig. **1** depicts the air velocity values at different locations along the length of the tunnel, but all of them at the ‘usual’ installation height of some 4.8 m. The two horizontal lines represent the boundaries of the acceptable air velocity range upstream the fire. This velocity band is according to [3] for unidirectional traffic 1.5 to 2.0 m/s. The majority of the lines (blue and red) are measurements at upstream locations. The air velocity stays more or less within the accepted velocity band. The yellow (orange lines depict the accepted accuracy of the measurement equipment. The test shows, that the required ventilation response is given. But there is one line showing a quite different behaviour – the green one. Shortly after fire ignition (‘Brandauslösung’ in Fig. **1**) the air velocity rises strongly. This is a measurement location some 300 m downstream of the fire. If such a value would be used for ventilation control the upstream velocity would be much too small and a big backlayering cone would be one of the results.

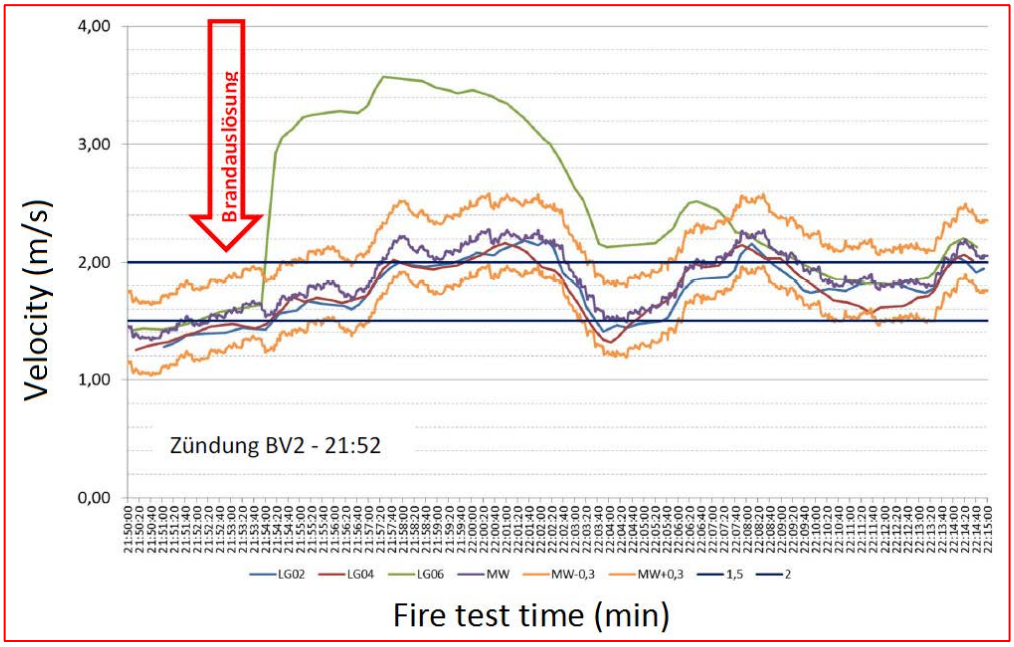


Fig. 1: Air velocity inside the tunnel at different locations during a fire test; courtesy of Lechner& Partner [2]

These results show clearly, that measurements performed downstream the fire can be strongly misleading. Any simple temperature correction would not be of help as the vertical profile and hence the volume flow is not known. Between fire and downstream measurement location no fans were active; hence an almost naturally driven layering could be established.

3. NUMERICAL SIMULATION

In order to get a better understanding of the length of the zone which might be impacted by thermal layers due to a fire, CFD calculations were performed. FDS version 6 was used for this task. In order to validate the CFD application, the test described in section 2 was used.

3.1. Tunnel geometry and FDS modelling

The simulation was based on the actual dimensions of the tunnel. The tunnel has a length of 1,300 m, a cross section of 52 m² and a circumference of 27.7 m. The tunnel tube considered for the simulation has a positive road gradient of 2%. Fig**. 2** shows the cross section and Fig**. 3** the plan view of the tunnel. Fig. **3** contains in addition the monitoring locations (point 1 to point 6 downstream as well as point 11 und 22 upstream of the fire location used for displaying the CFD results. Position 1 is equivalent to the position of the air velocity measurement location shown in Fig. **1** (green line, downstream location).

The tunnel has a horse shoe profile, which can't be resolved from the FDS due to the rectangular grid structure.

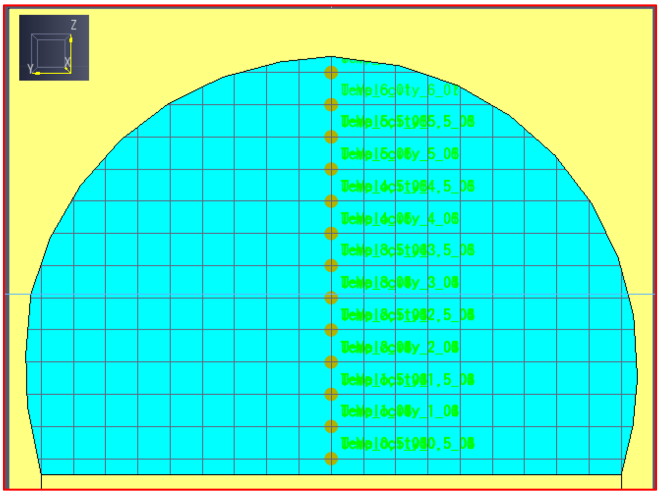


Fig. 2: Used cross section form for simulation modeling by FDS

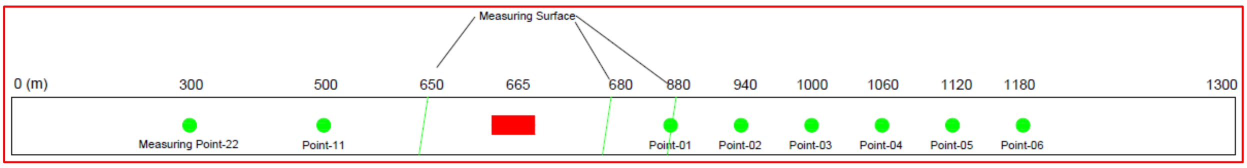


Fig. 3: Tunnel plan view, fire location (red square) and FDS monitoring cross-sections (green points)

3.2. Fire source and HRR

The fire is located 665 m after the entrance portal and has a central position. The first calculation concerned the validation of the model using the test as described in section 2 for this purpose. According to the RVS 09.02.31 [3] the fire source consists of two pool fires with an area of 1 m² filled with 20 l diesel and 5 l gasoline each. The HRR rate is assumed to 3 MW with a burning time of roughly 20 minutes. The second calculation used a HRR of 30 MW, while in a third one the influence of active fans on the temperature and U-velocity profile was investigated.

In order to allow for a uniform air flow development in the tunnel the heat release started 600 s after the start of the calculation.

As these calculations shall show only the principles of the development of the air flow, the fire source was simply be represented by a volume source with a specific HRR, combustion processes were not considered. Fig. **4** shows the HRR boundary condition for the 30 MW case. The maximum HRR was achieved within 180 s and remained constant for the rest of the simulation time.

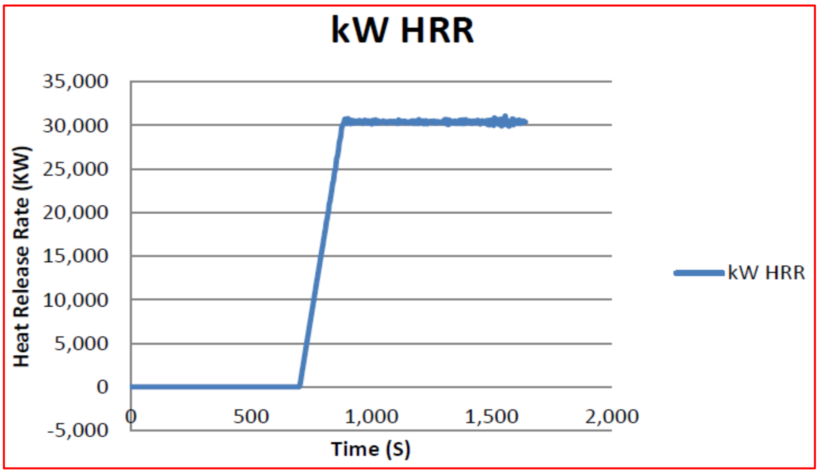


Fig. 4: Boundary condition for the HRR, simulation case 30 MW

3.3. Inlet and exit boundary condition

In order to allow for a quick consolidation of the airflow inside the tunnel before the fire starts a mass flow boundary condition was set at the entrance portal. After achieving a constant flow within the tunnel, the boundary condition was changed from fixed mass flow to 'open' in order to allow the flow to develop according to the evolution of the fire. Exit portal boundary condition was again 'open'. The incoming air has a temperature of 6°C, wall temperature is assumed to be also at 6°C.

3.4. Simulation results

Simulations were performed for the 3 MW case for model validation and for the 30 MW case in order to show how the air flow will be disturbed in case of a bigger fire. For both cases almost natural flow behaviour was simulated as it was observed during the validation experiment. An additional test case was performed in order to demonstrate the influence of active jet fans downstream the fire location but upstream the air velocity measurement location.

3.4.1. 3MW fire simulation

This case was used for validation the FDS application. The validation case is the 3 MW fire according to the RVS certification procedure [3]. The test results performed in the Niklasdorf tunnel is described in section 2. The calculation results will be shown for the locations 01 and 04 at a distance of 215 m (880 m from west portal) and 395m (1060 from west portal) downstream the fire (see Fig. **3**).

Fig**. 5** depicts the evolution of the U-velocity at cross section 01 at various heights between simulation start and 2,500 s. Before fire starts (at 600s), the air velocity distribution is quite uniform, between 1 and 1.5 m/s dependent on height, temperature is kept to 6°C. After the start of the fire there is a strong transient behaviour at the beginning. However, after some time an almost steady state situation is achieved. Wind speed varies between quite small values at the bottom and 2.7-2.9m/s close to the ceiling (note that slip condition which is applied in FDS as boundary condition for the wall influences the result negatively). Temperature varies between 10°C close to the bottom and 27°C close to the ceiling.

Fig**. 5** depicts the profile for U – velocity and temperature at the centre line of cross section 01. The measurement of the velocity during the experiment was taken at a height of 4.8m above ground. According to Fig. **1** the U-velocity value peaks at around 3.0 to 3.5 m/s (±0.1), temperature at that location was recorded around 25°C(±4). This fits quite well to the simulations.

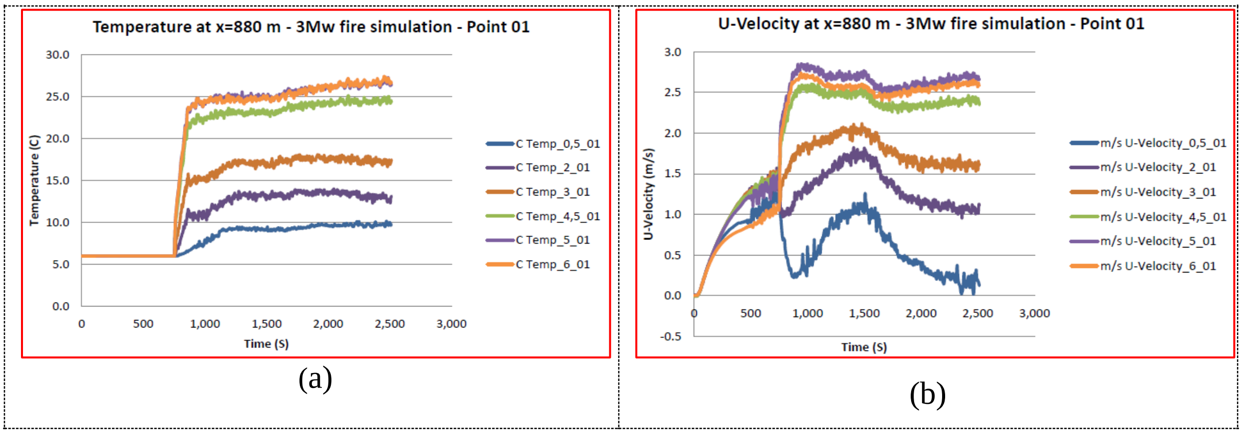


Fig. 5: Temperature (a), U-velocity (b) at tunnel cross section 01, 3MW case

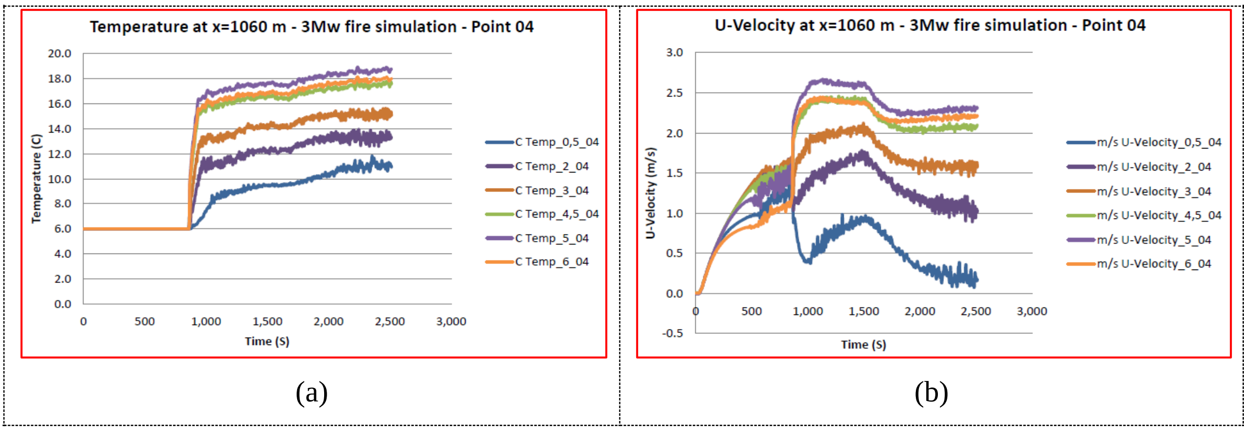


Fig. 6: Temperature (a), U-velocity (b) at tunnel cross section 04, 3MW case

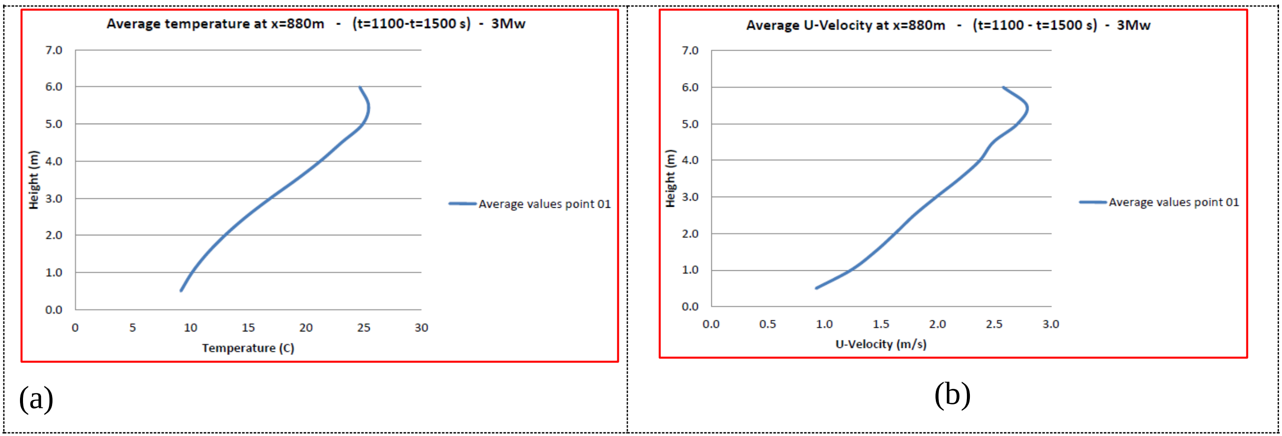
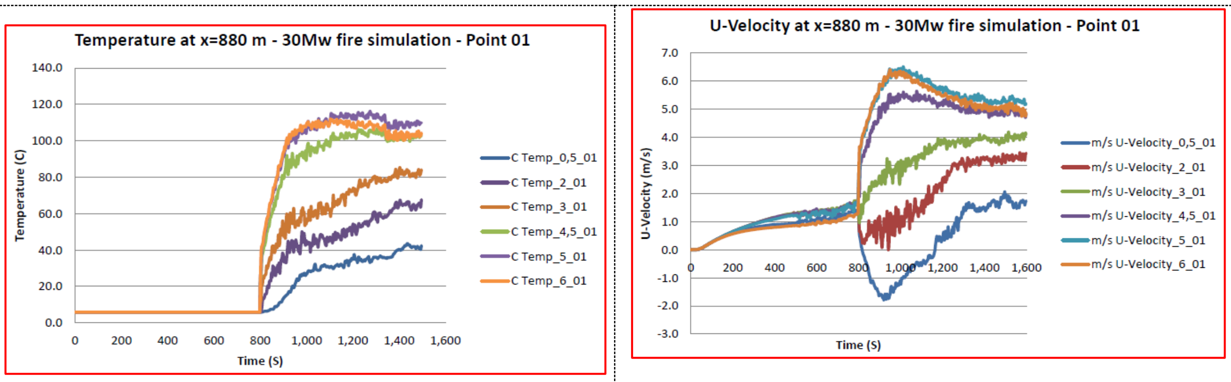


Fig. 7: Average values for Temperature (a), U-velocity (b), at tunnel cross section 01, 3MW case

3.4.2. 30MW fire simulation

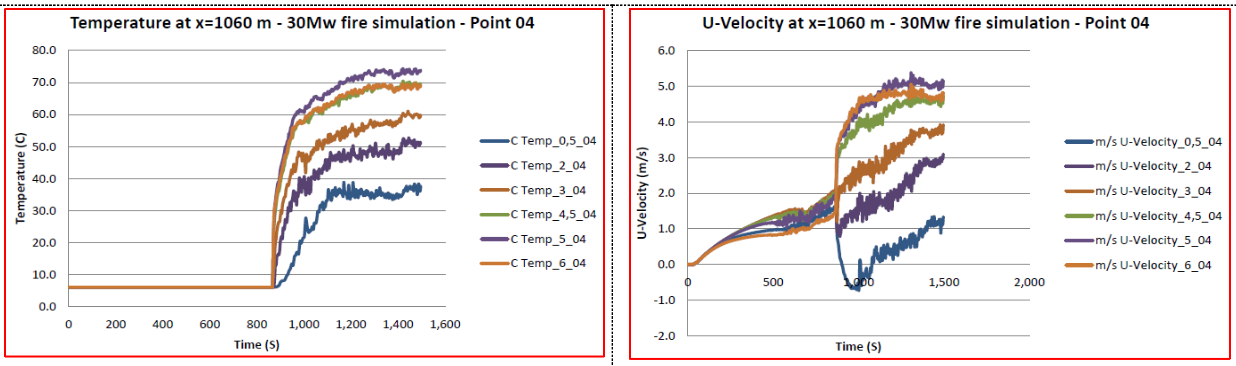
The standard design fire size for road tunnels in Austria is a 30 MW HRR representing a truck fire. Taking the same boundary conditions (except the HRR) as described above the following results were simulated.

Fig. **8** depicts air velocity and temperature at cross section 01 (+215 m, downstream). Air velocity rises from some 2 m/s at ground level to more than 5.3 m/s in 5.5m, temperature rises from 45 to 110°C for the steady state case. A quite similar situation appears also at the more remote location cross section 04 (Fig. **9**).



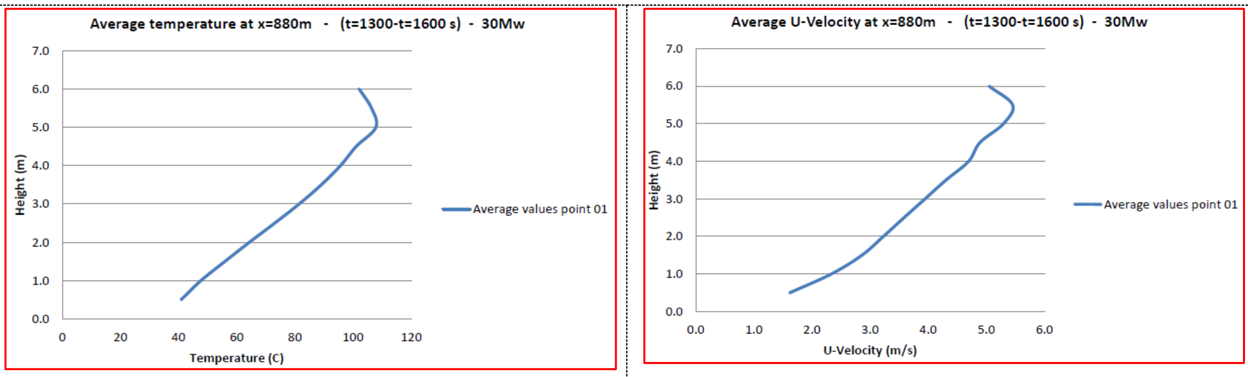
(a) (b)

Fig. 8: Temperature (a) and U-velocity (b) at cross section 01, 30MW case



(a) (b)

Fig. 9: Temperature (a) and U-velocity (b) at cross section 04, 30MW case



(a) (b)

Fig. 10: Average values for Temperature (a), U-velocity (b), at tunnel cross section 01, 30MW

Fig. **10** depicts the profile for U – velocity and temperature at the centre line of cross section 01. There is a quite strong gradient with height. If now a measurement for ventilation control must be taken from such a location downstream the fire the value is much too high. Instead of displaying the required 1.5 to 2 m/s upstream the fire almost 5 m/s are recorded. Even when taking the temperature reading (~100°C) into account, a temperature corrected value would still be around 4 m/s. Hence any control system based on this information would reduce the velocity of the incoming air, resulting in a big backlayering zone upstream the fire.

While this wrong behaviour of the ventilation control system would result in an unwanted backlayering in longitudinal ventilated tunnels, the negative effects in transverse ventilated tunnels could be much worse. It could lead to a strongly reduced extraction of smoke in favour of clean air from the other side of the extraction openings (dampers). Such malfunctions could be fatal.

3.4.3. 30W fire simulation with active fans downstream the fire and measurement location

The following scenario should show the effect of active fans downstream the fire and measurement location. The scenario is based on a 3 MW fire, an air velocity monitoring location downstream the fire at position 01 in Fig. **1** and a pair of active jet fans some ~ 350 inside the tunnel at downstream location (around 1000 in Fig. **1**). Such a scenario would be applicable in tunnels with unidirectional traffic (assuming no vehicles are between incident and exit portals) but should be avoided in tunnels with bi-directional traffic do to down-mixing of smoke in areas where traffic is stopped.

Fig. **11** depicts the profile for U – velocity and temperature at the centre line of cross section 01. Contrary to the cases discussed above, the active fans increase the turbulence downstream the fire and hence a much more uniform distribution of temperature and U-velocity over the height. When correcting the locally measured velocity with the temperature the resulting air velocity for smoke control is much closer to the control value needed upstream of the incident.

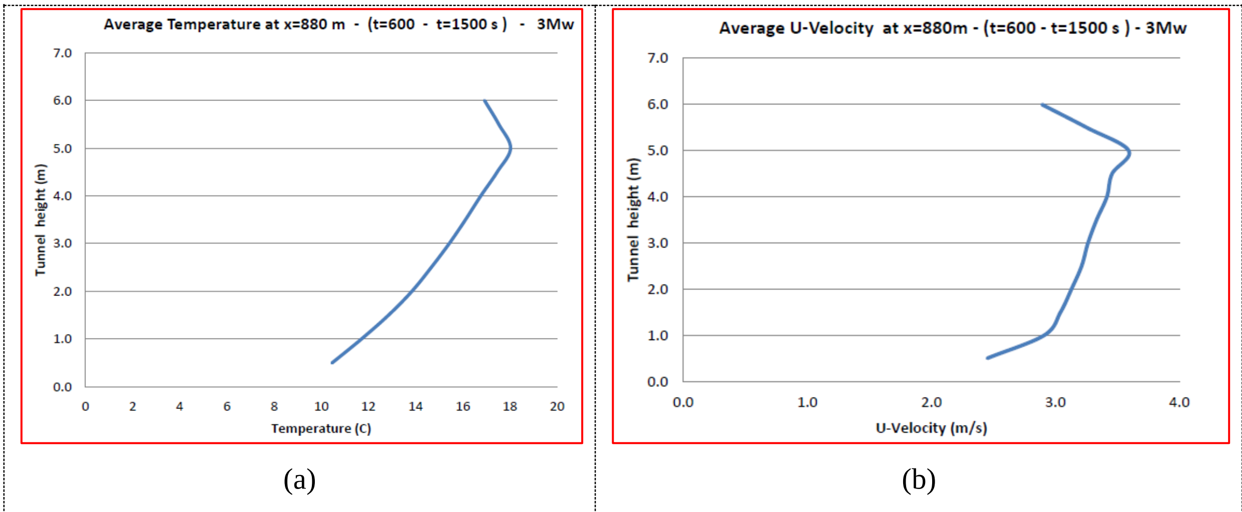


Fig. 11: Average values for Temperature (a), U-velocity (b), at tunnel cross section 01, 3MW case with active fans downstream

4. CONCLUSION AND RESULTS

Active (closed loop) ventilation control relies on correct measured values of the air velocity upstream an incident with a fire. Regardless which ventilation philosophy is applied, it is always the air velocity value, which is the input parameter for the control system. In standard tunnels such sensors are installed at multiple locations, hoping that one set of sensors is out of the zone which might be influenced by the fire. Any location fare enough upstream the fire would fulfil this requirement. However, due to unfavourable location of the incident or sensors with malfunctions or simply sensors being out of order, a second choice sensor on less appropriate locations has to be taken for redundancy purposed. However, if such a redundancy sensor lies within a smoke layer (downstream the fire) the reading will be strongly influenced by the absolutely non-uniform velocity and temperature profile at such a location. In cases with an almost natural flow between fire and monitoring location (no active fans in between), the values recorder will be much too high and a it is almost impossible to use them for ventilation control purposes. The simulation showed that is such cases increased turbulence due to active fans will reduce this problem. That means that for ventilation control purposes it might be necessary not only to switch sensors in case of malfunction of the main sensor, but also to change the priority tables for fan activations, in order to achieve a more or less acceptable ventilation control.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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