JET-FAN SYSTEMS IN SPRINKLERED CAR PARKS

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Summary: Ventilation systems with jet fans have been installed in thousands of car parks worldwide. Although the ventilation system with jet fans is widely accepted, discussions remain on the different types of smoke ventilation systems with jet fans and their interaction with sprinkler systems.

Keywords: enclosed car parks, smoke ventilation, smoke control, jet fans, sprinkler systems

1. INTRODUCTION

Enclosed underground car parks are a key part of the urban infrastructure. With the development of large retail parks, office buildings, and residential buildings, in urban areas, the requirement for parking space is high where space is limited. Therefore, many buildings are designed with enclosed underground car parks. Ventilation of car parks is necessary to prevent high concentrations of toxic exhaust fumes. Furthermore, in case of a fire, the ventilation system is used to exhaust smoke from the fire compartment. Traditional enclosed car park ventilation systems use ducted ventilation to provide an air change rate for the extraction of both exhaust fumes and smoke within the car park. These ventilation ducts must be evenly distributed around the car park at both high and low level, resulting in bulky ductwork systems. Accommodating these ducts can be problematic due to the low heights in most car parks and low level ducts can be subject to damage from vehicles. In 1995, Novenco was the first to design a jet fan based (smoke) ventilation system for car parks. By using jet fans to transport the air throughout the car park, these bulky ductwork systems can be avoided.

1.1. Synonyms

Synonyms for jet fan based ventilation systems:

- Impulse ventilation system
- Induction ventilation system
- Jet ventilation system
- Thrust ventilation system

These systems are all based on the same basic principle; inducing the surrounding air by means of small fan units that boost air with a relative high air velocity and induce the surrounding air in the same direction.

1.2. Basic principles of ventilation with jet fans

The concept of ventilation with jet fans requires some explanation. The function of jet fans is based on the impulse principle. From a small surface area (fan outlet) air is discharged at a relatively high velocity. When this air collides with the air in front of the fan, it thrusts the air forwards while at the same time drawing the surrounding air along with it (induction effect). Therefore the surrounding air will be moved in the direction of the airflow. As a result of this induction or entrainment, the quantity of air in motion will always be considerably larger than the quantity of air passing through the fan itself.

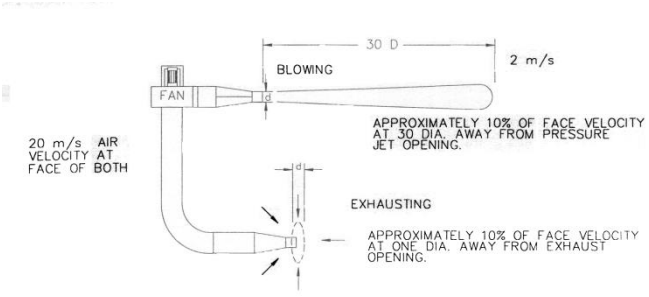

Fig. 1. Fundamental difference suction vs discharge

This driving force is called the thrust or impulse force of the jet fans and is expressed in Newton [N]. The thrust is the product of the mass flow rate and the change in velocity. It is the unit of measurement for jet fans, in contrast to conventional fans whose output is measured in volume

flow [m³/s] and pressure [Pa]. In theory, assuming that the surrounding air has zero initial velocity, the thrust generated by a jet fan is equal to the product of the volumetric air flow rate, the air density and the outlet velocity of the jet fan.

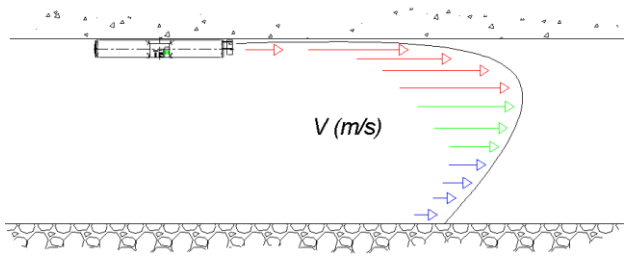

Fig. 2. Jet fan induction

The influence of the jet fans on the surrounding air is only local. The effective working area of the jet fans is depending on the type and function of the ventilation system. The jet fans are placed at strategic positions to ensure air movement and mixing throughout the car park. The combination of this thrust ventilation principle with mechanical exhaust and (natural and/or mechanical) fresh air supply results in an optimal ventilation system for enclosed car parks.

1.3. Advantages of ventilation with jet fans

A ventilation system with jet fans offers numerous advantages over conventional ducted ventilation systems for car parks:

- Space saving; the function of complex ductwork throughout the car park, taking up valuable space which is already restricted, is replaced by jet fans.
- Flexible installation; positioning of the jet fans is very flexible and can easily be coordinated with other systems within the car park.
- Optimal ventilation; because the jet fans efficiently mix the exhaust fumes with the surrounding air, high local concentrations of toxic gases are prevented.
- No dead spots; because jet fans can be placed in parts of the car park with limited ventilation, the build-up of high local concentrations are prevented.
- Energy savings; compared with ventilation systems with ductwork, relevant energy savings can be achieved.
- Cost savings; both during design and installation the (re-)positioning of the jet fans is very flexible.
- Smoke control systems are possible.

2. SMOKE VENTILATION

In accordance with the British Standard BS 7346 part 7 (2006), car park ventilation systems can be designed for one or more of three objectives in the event of a fire:

1. Assist fire-fighters to clear smoke from a car park during and after a fire;
2. Provide clear smoke-free access for fire-fighters to a point close to the seat of the fire;
3. Protect the means of escape from the car park.

With regard to objective 3 it must be noted that the ceiling height for an average car park is only 2,5 – 3,0m and therefore the height of an eventual smoke free layer is only very limited.
Depending on the design objective, the car park smoke ventilation system has to be designed as:

1. smoke clearance systems (objective 1);
2. smoke control systems (objective 2);

2.1. Smoke clearance systems

Smoke clearance systems are intended to provide ventilation to allow speedier clearance of the smoke once the fire has been extinguished. The ventilation might also help reduce smoke density and temperature during the course of a fire.
Smoke clearance systems are not engineered solutions. This means that the smoke extract rate is provided in standards, guidelines or the building regulations. In most European countries a minimum smoke ventilation rate per fire compartment of 10 air changes per hour is required:

$$Q_v = ACH \; x \; V_c \qquad (1)$$

$$V_c = A_c \; x \; h_c \qquad (2)$$

Where:

- V_c : volume car park / fire compartment [m^3]
- A_c : floor area [m^2]
- h_c : height [m]
- Q_v : required smoke ventilation extract [m^3/h]
- ACH : air changes per hour [h^{-1}]

These systems are designed for objective 1 of the BS 7346 part 7 and are therefore not specifically intended to maintain any area of a car park clear of smoke, to limit smoke density or temperature to within any limits.
To avoid smoke circulation and descent of the smoke layer during evacuation (objective 3), it might be preferable to either delay operation of the jet fans after automatic actuation or to provide only manual actuation from a fire service override switch.

2.2. Smoke control systems

Smoke control systems are provided specifically in order to assist fire-fighters to carry out fire-fighting operations. Due to the low heights in car parks vertical smoke control with a smoke-free layer is not possible. Therefore in a car park smoke control is horizontal rather than vertical. The system is designed to operate automatically in case of a fire detection and ensures clear, smoke-free access by fire-fighters to a point close to the seat of the fire.
Primarily, such systems will assist fire-fighting by:

1) Detecting the origin of the fire to a specific location in the car park;
2) Moving the smoke and heat from that location towards a specific extraction point or points;
3) Creating a smoke free approach zone or bridgehead clear of the fire. This allows fire-fighters to assemble personnel and equipment in favorable conditions and fire-fighting operations to be carried out more quickly, safely and efficiently.

The basis of the design is to prevent the smoke from back layering against the ventilation airflow by maintaining a critical air velocity. This minimum critical velocity is dependent on a number of factors, due to which smoke control systems are always fire engineered solutions:

1) What is the maximum fire size?
2) Is there a sprinkler system to limit the fire size?
3) What if the fire spreads to other cars?
4) Where are the escape / evacuation routes?
5) How long will it take to evacuate the car park?
6) What is the reaction time of the fire brigade?
7) Where are the attack routes for the fire brigade?
8) Where can smoke extract and air supply be planned?

In large or complex car parks where jet fans are employed, there might be multiple extraction points. Smoke control systems can be designed to be fully reversible to move the smoke in one of several directions, depending on the location of the fire. Again it is important to ensure that there are suitably located fire-fighting access points to allow the bridgehead to be created for each design fire scenario considered.

Fig. 3. View of the seat of the fire with smoke control

To protect the means of escape from the car park, it is advisable that upon fire detection only the main extractors and supply are put into operation. This will not disrupt the stratification despite a portion of the smoke gases being extracted quickly. Jet fans should always be switched off during this evacuation period to avoid smoke circulation and cooling and thus the descent of the smoke layer into the occupied space. Once the jet fans have been switched on, the smoke will quickly spread to the downstream section.

Although the jet fans change the velocity distribution they are only of limited (local) influence on the main airflow through the car park. This main average airflow is to a significant degree determined by the smoke extract rate of the main extractor fans in combination with the makeup air intakes.

Through induction and mixing, the jet fans provide a considerable reduction in smoke temperatures. By reducing the smoke temperatures, the level of smoke back layering against the ventilation airflow can be reduced, providing the fire brigade with improved conditions for firefighting. The increased airflow with smoke control will not increase the fire size since it is limited by the fuel, which is the material from the burning car. Inside the car park there is enough oxygen available to feed the fire.

Novenco has proven the smoke control system with full-scale fire tests, in an enclosed car park, in 1998. During these fire tests in total 18 passenger cars were burned by an independent body (TNO – Organization for Applied Scientific Research) commissioned by the fire brigades and Dutch ministries. Conclusions of the tests:

- Conventional duct-based ventilation systems are unsuitable for smoke control purposes, even with air change rates of 10 times per hour. The entire area quickly becomes filled with smoke and locating the fire is very difficult.
- Smoke control is possible with engineered solutions with high smoke exhaust rates based on critical air velocity over the fire in combination with active cooling of the smoke with jet fans.
- During the evacuation period, the jet fans must be switched off to prevent mixing of air and smoke.
- By running the exhaust, supply and jet fans at full speed after evacuation is complete, the spread of smoke can be kept within a limited area. The fire also remains visible at all times.
- Fire development can be observed during the entire extinguishing process, providing improved safety for the firefighters and faster fire extinction.
- Smoke control systems can effectively cool down the smoke by mixing smoke with surrounding (cold) air.
- After extinction, visibility within the car park will quickly increase providing emergency services with improved sight conditions.

It must be noted that although smoke control systems offer great benefits for the fire brigade, the design may have an impact on initial costs of the installation. The reason is that for smoke control systems higher exhaust rates are necessary, as a result of which among others the size of the structural shafts will increase.

3. DESIGN FOR A FIRE

The extract rate for a smoke clearance system is relative to the size of the car park whereas a smoke control system is designed to extract smoke for a given fire. As a starting point the fire size from the BS 7346-7 can be adopted:

- 4MW for a car park with sprinklers, or;
- 8MW if sprinklers are not provided.

A fire engineered approach, to the design of a smoke control system, will require the design to be based on an agreed fire load. This approach can also be used as a compensating feature for relaxations to the normal requirements of the national or local building regulations, such as for example the requirement for a sprinkler system for the car park.
A fire engineered approach may suggest that the sprinkler system is replaced by a smoke control system, but that is not the case. Whereas sprinkler system is aimed at property protection by preventing the fire from spreading, and limiting the fire size and limiting the heat release rates, smoke control systems are aimed at providing smoke-free access, for fire-fighters, to a point close to the seat of the fire. It is this compensating feature in relation to the 'normal' regulations that provide the relaxation of other requirements.

3.1. Sprinkler systems in car parks

There is an important distinction to be made for sprinkler systems in car parks.
Firstly automatic fire suppression sprinkler systems are very effective in temperature control and prevention of fire spreading to other vehicles. If sprinklers are activated in the early stages of a fire, the fire size can be kept under control, and the heat release rate limited.
Due to the cooling effect of the water, mainly due to the latent heat of evaporation, temperatures are kept to acceptable levels and the fire size is controlled. Fire tests on cars in buildings with sprinklers have shown that the spread of fire between cars does not occur with an activated sprinkler.
However, in most car fires, the fire source is either inside the car or in the engine compartment. Therefore a sprinkler system is not effective as a means of extinguishing the fire, as the sprinkler cannot deliver water onto the seat of the fire, as the fire is covered protected by the actual bodywork of the car. With a sprinkler system there is a real chance of combustion of flammable liquid - e.g. by rupture of the fuel tank - the so-called "pool fire". Initially, the fuel is a liquid, and the application of a stream of water will splash it and spread the fire. Another consideration is that the water will not cut off the oxygen supply as the fuel will not be "blanketed" by the water (fuel floats on water as it is less dense).
Because of the material composition of modern cars containing significantly more plastics, smoke production will prevail over temperature. With the fire source inside the car or under the hood, temperature radiation will be limited, but smoke production will increase dramatically.
In the case where the sprinkler detection is used to trigger the evacuation alarm, fire detection could be very late because of relative low smoke temperatures. In such a case there will be a lot of toxic smoke in the car park making evacuation and repression difficult.
Confusion about the location of the fire can lead to a delay in the deployment of the fire brigade. Because of the dense smoke it is often not possible to find the exact fire location quickly.
During the containment period, excessive amounts of steam can be produced which may last more than an hour. This will limit intervention by firefighters as the location of the fire is not visible.

3.2. Smoke ventilation with jet fans in sprinklered car parks

International rules, such as NFPA, BS and the German GarVo require that smoke ventilation is required with sprinkler systems. However the requirement is mostly for a smoke clearance systems, which are not suitable for the objective of smoke-free access for fire-fighters to a point close to the seat of the fire.
Combining sprinkler systems with a smoke control system may result in having the best from both worlds:

- Sprinkler systems can control the fire size;
- Sprinkler systems can prevent the spread of fire to other cars;
- Sprinkler systems can lower smoke temperatures;
- With lower fire sizes and temperatures, the critical air velocity to prevent back layering of smoke is lower;
- Smoke control systems can be designed at lower airflows since critical air velocities are lower;
- Smoke control systems can contain the smoke and steam created by the sprinkler in predefined zones and therefore structural fire walls and fire doors may no longer be necessary;
- Smoke control systems can provide smoke-free access for fire-fighters resulting in rapid deployment of the fire brigade;
- By using electronic fire detection systems, a car fire can be recognised and localized by which an effective smoke control ventilation and deployment of the fire brigade can be started. Furthermore an evacuation alarm can be triggered in the early phases of a fire.

Fig. 4. Fire source inside the car

As such a sprinkler system may serve very well and complementary to a smoke ventilation system with jet fans. But it is of the essence that both systems are designed and installed in such a way that they do not have a negative effect on each other.

3.3. Influence of jet fans on sprinklers and vice-versa

A sprinkler is triggered by temperature. Smoke exhaust systems are (preferably) triggered by electronic smoke detection systems to ensure an early detection and start of the evacuation and smoke extract. Therefore it is reasonable to assume that in case of a car fire in an enclosed car park, the reaction time of a smoke detection is much shorter than a sprinkler. To ensure optimal function of both systems, the following has to be taken into account:

- influence of the jet stream on the sprinkler;
- influence of the sprinkler on the smoke;

For the daily (CO) ventilation a jet fan system shall have a limited air velocity in the car park. Also in relation to fire safety this is very important:

- Lower air velocities will limit smoke spread in an early stage of the fire to optimize evacuation conditions.
- For correct smoke detection, low air velocities will prevent the smoke from spreading before detection.

Therefore the thrust of jet fans in low speed should be limited to max. 20N (CO ventilation) and to max. 50N for the high speed (smoke ventilation). Furthermore, the position of the jet fans in the car park should be coordinated with the parking spaces and smoke detectors. By placing the jet fans over the driving lanes and not over the parking spaces, the risk of having a jet fan in the direct vicinity of the car fire is minimized and therewith also the risk of influencing detection and sprinkler activation.

A big driving force for the movement of heat and smoke in case of a fire are the buoyancy forces due to the differences in air densities created by the temperature of the smoke. As long as the smoke temperature is higher than the adjacent ambient air, the smoke will remain buoyant and thus expand in all directions.

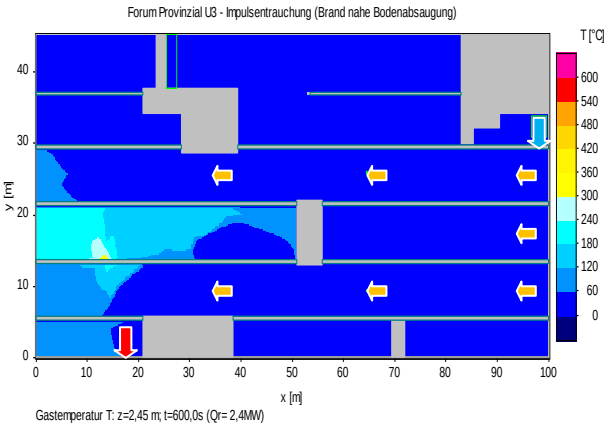

Fig. 5. Temperature (°C) after 10min with smoke control system

These buoyancy and entrainment forces generated by the fire will compete against the ventilation airflow and impulse force by the jet fans. For the jet stream to influence the sprinkler activation, the force of the jet stream should therefore be higher than the buoyancy force directly over the fire source. CFD simulations show that even with a smoke control system with jet fans fully activated, the temperatures directly above the fire will be sufficient to activate the sprinkler within 5-10min after start of the fire. In figure 5 the temperatures are shown for a car fire after 10min. Due to the buoyance forces of the hot smoke, the smoke also expands against the jet stream until the smoke is cooled down sufficiently to be controlled. Therefore jet fans will not interfere with the sprinkler activation above the fire source in case of a fire.

However, a delay in starting the jet fans of 5-7min after detection would be advisable for two reasons:

1) Delay of activation of the jet fans provides the best evacuation conditions upstream and downstream of the fire;
2) Delaying activation of the jet fans can avoid causing a delay in activation of the sprinklers, in the areas close to the seat of the fire

In case the fire source is very close to a jet fan, the force implied by the jet fan on the smoke will be very limited due to the low air density, since:

$$T_j = Q \; x \; v_o \; x \; \rho \qquad (3)$$

Where:

- T_j : thrust of the jet fan [N]
- Q : airflow of the jet fan [m^3/s]
- v_0 : outlet velocity of the jet fan [m/s]
- ρ : density of the air / smoke [kg/m^3]

Since density decreases at higher temperatures, the thrust of the jet fan also decreases where the buoyancy force of the smoke increases. Therefore also the influence of the jet stream on sprinkler activation decreases.

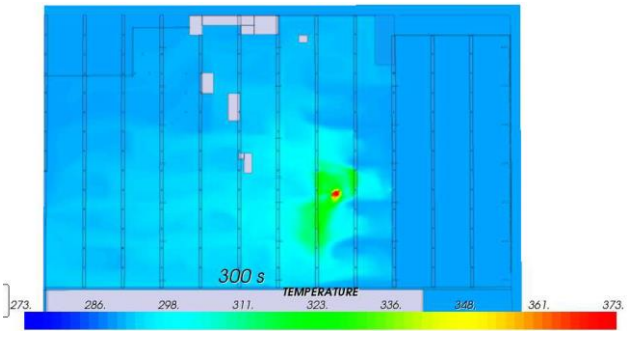

Fig. 6. Temperature (°K) after 5min with smoke control system

Furthermore, if the temperature for sprinkler activation is not reached, there is no need for the sprinkler to be activated and consequential damage due to (polluted) water is prevented. Also figure 6 confirms that sprinklers would only be activated locally around the fire and therefore the

effect of the sprinkler on the smoke ventilation system can be neglected. Around the fire, smoke 'washing' can be expected, which will decrease the view on the seat of the fire. But because of lower smoke temperatures with sprinkler, a smoke control system with jet fans for smoke-free access for fire-fighters can be designed at lower critical air velocities and thus lower smoke extract rates, resulting in smaller smoke extract shafts and less jet fans.

3.4. Time sequence for sprinkler and (jet) fans

Where automatic fire sprinklers operate at a predetermined temperature, smoke ventilation systems require some sort of activation signal from an automatic smoke or fire detection system. Full-scale fire tests with cars show that with a fire inside the car or under the hood, the fire starts with huge smoke production. Temperature increase will occur in a much later stage of the fire. Life safety should be priority and automatic smoke and/or fire detection systems will provide the best possible means of escape and can mean the difference between life and death.
Considering the complementary systems of automatic detection systems, smoke (control) ventilation with jet fans and sprinkler systems the time sequence is a very important issue for providing the best possible means of escape in case of a fire.

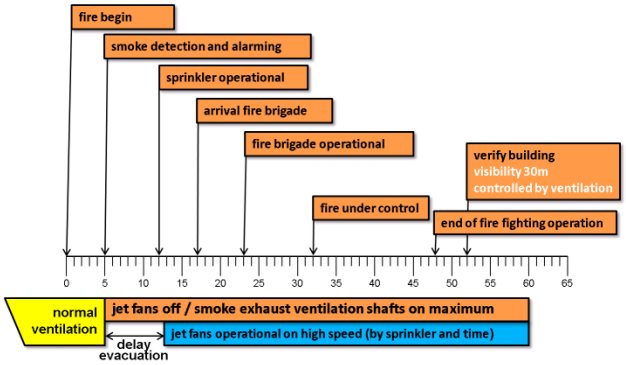

Fig. 6. Timeline with sprinkler and smoke ventilation

Figure 6 shows an example characteristic timeline for a fire with sprinklers and a smoke control system with jet fans. The times shown are just indicative and may not apply to all situations and are among others depending on:

- The type of fire;
- Type of detection system;
- Evacuation distance to nearest exit;
- Response time of the fire brigade;

In this characteristic timeline the normal ventilation is running when the fire starts. In a chronological sequence the following steps are taken:

- Depending on the amount of smoke/temperature and detection settings of the automatic fire detection system, the fire will be detected after a certain time period (in the example 5 min after start of the fire);
- Upon fire detection, the evacuation alarm signal for all the occupants is activated, the fire brigade is alarmed and the ventilation system is shut down;
- Depending on the fire zone and level, all necessary dampers in the ventilation system are set to extract the smoke from the compartment / level where the fire was detected;
- After these system settings the smoke extract fans are started on maximum capacity;
- Eventually necessary mechanical supply is started immediately after the mechanical exhaust is running;
- The jet fans will remain off to prevent a negative influence on the means of escape (smoke free layer);
- Depending on the temperature rise, sprinklers may be activated to control the temperature and minimize the fire growth;
- Jet fans are activated 5-7 min after detection*, depending on the required evacuation time;
- Depending on the response time of the fire brigade, they will arrive on site and assess the situation;
- Within the minimum time required, the fire brigade will become operational;
- With the sprinkler system controlling the fire size, growth and temperature and the smoke control system with jet fans providing a the fire-fighters with a smoke-free access to a point close to the seat of the fire, the fire brigade will have the best chances to get the fire under control shortly after;
- The smoke control ventilation system with jet fans will remain operational throughout the deployment of the fire brigade;
- After the fire has been extinguished, the smoke control system will clear the car park in a matter of minutes from smoke, after which the building can be verified;
- Depending on the damage, the building can be taken into operation again shortly after.

*) Jet fans will also become operational if the sprinkler system has not been activated. This because the jet fans will have no negative influence on the sprinkler activation, but can be of influence on providing the best possible means of deployment for the fire brigade.

4. CONCLUSIONS

With underground enclosed car parks becoming the standard parking facilities in urban areas, car park safety is a growing area of concern. Fire loads of cars constantly increase because of the size of the cars and the amount of plastics and other combustibles used in passenger cars. Current standards and regulations are different worldwide, ranging from sprinklered car parks without any

form of smoke ventilation to car parks with smoke ventilation systems but without sprinkler systems. There is no right or wrong, since both systems have different objectives and can therefore not be compared.
First and foremost is a safe evacuation of the occupants in case of a fire. For that purpose automatic fire detection systems are very useful.
To assist the fire brigade, smoke control systems with jet fans can be designed to provide the fire brigade with a clear smoke-free access for fire-fighters to a point close to the seat of the fire. To prevent high fire loads and spread of the fire, a sprinkler system may serve as a valuable addition to a smoke control system with jet fans.
The two systems should be complementary to each other and already during the initial design phase the positioning of the sprinklers and jet fans should be coordinated.
By delaying the jet fan operation, negative effects of the jet fans on the evacuation and sprinkler operation can be avoided.
By combining automatic fire detection systems, sprinkler systems and smoke control systems, future car parks will benefit from optimal fire safety, minimal casualties and optimal conditions for the fire brigade in case of a fire.

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