THE DESIGN OF MORE SECURE PRESSURIZATION SYSTEMS IN
STAIR CASES OF HIGHRISE BUILDINGS

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Introduction
In high rise buildings it is essential that exit staircases remain free of smoke during evacuation. Around the world, pressurizing systems are often used to keep exit stairs in tall buildings smoke free. The design of pressurization systems are not easy, because of the stack effect, horizontal air flow in staircases, due to temperature difference between outside air during cold or warm weather conditions and conditioned air inside the building. This effect has the potential of overcoming the overpressure in the staircase and allowing smoke entry from the fire floor into the staircase, or unacceptably high opening forces to enter the stairs, possibly preventing a safe evacuation.

DGM Consulting Engineers was involved in the design and testing of a pressurization system of the staircases of a highrise office building in The Hague. Limitations imposed due to late introduction in the building process lead to a design that may offer a solution for the difficulties in the design of pressurized stairs.

Pressurization system
A pressurization system should function in two different settings to prevent smoke to enter a staircase. In the situation where all stair doors are closed, the system maintains a pressure difference between the staircase and the fire floor. During the evacuation of a building or during fire fighting procedures, the door between the fire floor and the staircase inevitably will be opened. In that case the system should provide an air flow from the staircase to the fire floor, preventing smoke ingress in the staircase.

Design challenges
When DGM got involved in the project, construction work had started, and the building design did not contain any form of air release for the pressurization system. Half way through the building process exhaust slits were added to the building. Room for these slits was limited.

Analysis with building airflow model CONTAM developed by NSF revealed that the system would not function without extremely powerful fans in the air release shafts. The CONTAM model also pointed out that very high negative pressures would occur in the air release shaft and therefore also in the fire floor. This could easily lead to unacceptable high opening forces. The challenge here was to design a system that would never lead to blocked access doors to the staircases.

Another design challenge was imposed by the building having operable windows. This meant the pressurization system should be able to operate in the situation where all windows of the building were closed and the building is air tight, as well as in the situation where one or more windows were opened. The figures underneath shows the pressure difference gradient between the staircase and the floors in case of closed windows. Left: closed windows, right with open doors.

Finally wind will result in ever changing conditions in and outside the building.

Solutions
In one of the two towers the only solution was to dedicate a small storage room on every floor to the pressurization system. As mentioned before, because of structural reasons, the floors in the towers could not be larger than 0.5 m² in total in both towers. As stated, an analysis with building airflow model CONTAM showed that an extremely high pressure drop would occur in the 140 meters high shafts, caused by the exhaust air accelerating and decelerating on all floors. To prevent the necessity of even higher pressures a steel duct shaft was installed to smoothly guide the air up the shaft. High standards were imposed regarding the air tightness of the doors. Practical tests on the spot with pressure and leakage measurements were held to assure the shaft doors were air tight enough. These tests were also held to check that the doors and penetration seals would withstand the high negative pressure in the shaft.

Control system
When either the smoke detection system or the sprinkler system is activated on the fire floor, the shaft door on that floor is released. The fan of the air release shaft is turned on and starts to accelerate, which leads to increasing pressure difference between the fire floor and the stairs. At the same time the air supply fan is started which results in a positive pressure in the staircase. Both the air inlet shaft of the exit stairs and the air release shaft are supplied with a variable frequency drive (VFD). The VFD of the air inlet shaft adjusts the air inlet to the stairs and therefore the pressure. The positive pressure in the staircase is set on the pressure difference between the staircase and a reference line. The staircases are divided into three sections, separated by doors, the reference line was connected to a floor outside the section. E.g. the lower section ranges from the ground floor to the 11th floor, the reference line is connected to the 12th floor.

When the pressure in the air release shaft exceeds the airflow of the air release shaft, pressure differential gauges on every floor measure the pressure difference between the staircase and the fire floor. As the pressure difference increases above a certain value, and the air release shaft accelerates until, on any floor, the pressure difference exceeds a limiting value of 100 Pa. This limiting value is reached the fan of the air release shaft is shifted down.

When the stair door on the fire floor is opened, an air flow occurs from the staircase to the fire floor. The pressure in the staircase drops, both the fan of the air supply shaft and the fan of the air release shaft accelerates. When the stair door on the fire floor is closed, a peak pressure will develop that is picked up by the sensors. Both the air supply fan and the air release fan are ramped down within seconds. This causes a short period in which a lot of force is needed to open the staircase door. Because both the air inlet and the air release are measured and modulated separately, both access to the stairs and pressure difference is maintained. The principle is shown in the picture below.

Conclusions
Pressurization systems are difficult to design because of the impact of stack effect. For the new office building of the Ministries of Justice and Interior Affairs the Hague the challenges to be solved were the addition of air release shafts in a building that was under construction, the extremely high pressures that were expected in the air release shafts and the ever changing pressure differences as a result of wind and of open or closed windows.

A stair pressurization system was designed that will keep the pressure difference across the stair door below dangerous levels even under these adverse circumstances. The system set up guarantees an air flow across the door opening on the fire floor, also when doors on other floors are opened during evacuation.

Acknowledgement
A team, consisting of building services consultants (Deerns Installatie Engineers), contractor (JadT), system supplier (K-E-RT) and DGM Consulting Engineers, worked together to design and build a robust pressurizing system for the stairs in the building. As the building was under construction it fell under the regulations of the (R)ligbouwontwerp) and the project supervisor (Bink Groep) were very cooperative and supportive in the process.