Smoke Protection Pressure Systems in high Skyscrapers

„Lighthouse“ ECB in Frankfurt am Main

Smoke Protection Pressure Systems (SPPS) have become Industry Standard, securing safe Escape Routes via Staircases and Elevator Shafts in Case of Emergency.

Mathias Behrens,
Canzler GmbH - Mr. Behrens is head of the Canzler Dresden office, authorized representative and DGNB auditor as well as planner of approval documents for ventilation and air-conditioning. He planned SPPS in comparative buildings (e.g. IBC and *Eurotheum* in Frankfurt am Main).

As a planning- and consultancy company with an integrated approach and a workforce of 120 employees, Canzler developed sustainable and efficient solutions for future-oriented construction works.
As a first step in the ECB project, the building owner entrusted Canzler with the planning services; starting with mechanical trades, followed by building automation. Since other SPPS projects are already being planned by Canzler, the focus was laid on the adaption from similar projects.

Project Data

The project ´New Construction of European Central Bank Administrative Headquarters´ in Frankfurt am Main (Image 1) is characterized by two high rise blocks of just under 200m along with their linking via a joint atrium divided into four sections. The listed *´Großmarkthalle´* (former wholesale market) with a height of approx. 25m is particularly remarkable when it comes to its surface area of 60m x 250m. The whole project incl. competition, planning and execution took 9 years.

Function of SPPS

Primary safety objectives are fire protection along with keeping escape routes smoke-free, securing access to escape routes and firefighting entrances. The derived secondary safety objectives relate to smoke protection excess pressure in the staircase across the floor on fire with min. 15 N/m² as well as to smoke protection airflow from the staircase through open windows to the floor, where the fire is located with ≥ 2 m/s. It is also important that the opening of the doors along the escape route is aided by limiting their opening force to ≤ 100 N and their response time to < 3 s between the operating conditions ´protection flow´ and ´protective pressure´. 90% of the values need to be achieved in this given time frame. [1].

In case of smoke detection, the fire alarm transmits a signal to the safety-related control of SPPS. The so-called pressure ventilation generates excess pressure by blowing external air into the staircase and/or the air locks to the required corridor to protect from smoke. If the doors leading to the floor where the fire is located are open, air with 2 m/s flows from the smoke protected staircase into the respective floor filled with smoke, that needs to be drawn away from the required corridor. The fire alarm detects and moreover reports the floor assigned to the detector triggering the alarm (= level where the fire is located), as this information is relevant for SPPS´s pressure regulation function. Other systems are being controlled according to the fire control matrix by means of building automation. Facade elements of the floor on fire are thus opened by electrical drives while other facades are closed.

So far, no uniform guidelines have been established for the technical solution of smoke protection via excess pressure and directed flow along escape routes and firefighting accesses. Technical individual solutions are brought to the market much faster, because it takes more time until authorized operating experience is evaluated and turned into generalized standards. Solutions are to be tailor-made in accordance to the specific circumstances of the application and to the respective safety objectives.

Both high rise towers were equipped with two emergency staircases each, along with a firefighters lift with SPPS. Seven air purge systems are located within the *Großmarkthalle´* (former wholesale market) with similar protection requirements.

Much less than 1% of the total project costs were estimated for the SPPS. However, in case of emergency, these systems secure the escape or rescue of more than 2,500 employees, clearly underlining the great relevance of this system´s technology: No building usage without usable SPPS!

Challenges and Solutions

Planning focus:

Due to various interfaces, many project participants are involved in the SPPS planning. It is supposedly just one ventilation- and air-conditioning planner, who takes responsibility for SPPS planning – However, this is not at all the case.

SPPS planning is often neglected by creative architects in the light of secondary design demands (Image 2). However, SPPS requires solutions from coordinating architects in the areas of installation space, shafts and lines, façade openings, secure power supply, openings in the static related hard core and functional grilles with limited design flexibility. Unfortunately, this is usually not duly taken into account, neither throughout the process of the preliminary planning, nor in the architectural design or structural engineering, leading to complications at a later stage. Fire protection experts fix a considerable part of requirements for special constructions.
In cooperation with the expert for ventilation technology and building automation they are able to propose sensible detailed solutions. Also in the framework of the ECB project, the SPPS was – at times – not duly taken into consideration; As a result a time-delayed implementation became necessary.

Interfaces of Technical Trades

SPPS are not solely ventilation systems. There exist interfaces to the building structure (static), façade, doors, surfaces, building automation, and electrical connections. That is the reason why architects and specialist planners for ventilation and air-conditioning technology jointly determine the flow paths. Only in a common approach, architect and specialist planner are capable of integrating cross sections of this size at exposed positions (façade, building core) into the building.

In the case of the ECB project, the parties involved had configured the air outlet from the corridor for two SPPS as too small. As a result, in its position as project ´troubleshooter´, Canzler had to draft an alternative plan integrated into the existing architectural framework under difficult conditions in the execution planning.
In the end, four supporting fans with pressure control each became necessary, in order to secure proper functioning for the undersized flow areas.

Simulations

When it comes to geometrically complex and high-rising buildings, precise predictions on whether or not secondary safety objectives are being met prove to be very challenging. The planning only succeeds with complementing simulations. Project experience regularly shows that complex procedures can be predicted with great accuracy by realizing a careful data entry. It is then possible to set the course for the success of cost-efficient and needs-oriented solutions already at a very early stage. Different versions are ideally simulated as early as in the preliminary planning phase, facilitating the search of an optimal solution.
Simulations are only as good as their respective data input and thus to be created, to be monitored and finally to be updated according to structural changes by the expert planners. In the framework of the ECB tower project, an expert for flow simulations in design and execution planning was commissioned in order to prove the achievement of the secondary safety objectives. Thanks to the close support provided by

Canzler, simulations and their variants exactly mapped the property, finally leading to simulation results constituting a solid planning basis.

Leakages
The excess pressure only works with sufficiently reduced free cross section undesired concrete openings, dry walling, double bottom constructions, fireproof bulkheads, doors and façades. That is the reason why planning architects have to take a decision on the quality of the building´s tightness ([1], P. A6.2).

Those specifications had not been sufficiently defined in the course of the ECB project. Due to the leakages, characteristic in construction, the laid duct routes as well as the installed fans in two air purge systems were not large enough and thus required improvement.

Redirect volume flows based on need
The change between the OCs ´staircase protection pressure´ and ´protection flow on the level where the fire is located´ requires adapted control devices, in order to redirect the volume flows within 3 s.

Control butterfly valves with 2,5 s for 90° are fast enough, as the pulse starts to be effective already at ≥ 15° aperture angle – thus within one second. Apart from the control butterfly valves, the reaction times of the fans are also to be observed. The duration for the storage of movement activity in the rotating fan wheel requires constant rotation speed and control of constant volume flows (see image 3). In order to make sure, that SPPS attains the secondary safety objectives (pressure, flow, control rate), the external air fans were complemented by a bypass close) in the ECB project (see images 4 and 5).

Image 3 illustrates the conventional solution without bypass control incl. problems of excess door opening forces and switching time > 3 s. In a staircase with a relatively high pressure loss, the SPPS is unable to adequately react to switching procedures, that occur by opening and closing of the floor where the fire is located, in the event of escape.

Image 4 shows the OS protective pressure requirements. The reduced volume flow in the staircase enables the generation of sufficient protection pressure when door opening forces are kept up.

Image 5 illustrated the OS protection flow. The fan´s constant high volume flow enables the fast provision of protection pressure into the floor where the fire is located when opening the door.

Appropriate Reliability
Measures against failures are prone to considerably increase prices and complicate technologies. In view of two safety staircases (required by planning law) for high-rise buildings higher than 60m we look at a redundancy of n+1. Since the fire incident already constitutes one damaging event, no particular importance is attached to the scenario ´Additional Component Failure´. No risk may arise by component failure such as the moving of external air into the staircase while pressure relief flaps are kept closed by accident. The example of the parallel flow through pressure relief flaps with normally open spring return actuator at the

stairway head (Image 6) is supposed to demonstrate, that in most cases a partly redundant execution is sufficient by an examination of component failure.

Clarification of Operating Status (OS)
Fire protection expert opinions often demand the OS ´Rinse´ in addition to the SPPS function. This is to be defined. This is deliberate for manual release or fire in the atrium, as well as for scenarios without precise allocation of floor on fire. The follow-up scenario of a manually released ´smoke detection with allocation of the floor where the fire is located´ is to be agreed upon. It is moreover important, that the firefighting panels do not only display ´Off´ and ´Auto´ but also very clearly the OS ´SPPS on´ (OS with allocation of floor on fire)´and ´Rinse On´ (OS without allocation of floor on fire).

Door Opening Force and closure after usage

The opening force of the doors located in escape direction against excess pressure shall not exceed 100 N. This is why power from excess pressure and power for the tensioning of the overhead door closer (ODC) as well as the overcoming of static friction need to be involved in the planning. The secure closing of this door usually does not pose a problem. Attention should be paid to damping qualities of the often hard slamming doors. Due to the fact that even the door width has a considerable impact on the door forces, the layout needs to be designed early in the planning process.

The doors located in escape direction from the staircase protected from pressure are usually easy to open against the low pressure. Only ice, snow and grit are hampering factors. But are the ODCs really capable of securely closing the door and thus of securing protection pressure for the staircase? If wind power mounts pressure on the open door leaf, the efficiency of mechanical ODC is quickly reached, so that electrical assistance becomes necessary. It is to be individually coordinated which wind speed to be set. In individual cases, measurements of frequency, wind direction and wind speed may be of assistance, in order to assess the danger with regard to wind speed. A hazard analysis may serve as a basis for an expert approval. Image 7 shows the typical geometrical conditions of a 2 m² door and an ODC, trying to close the door with 60 Nm. At a wind speed of 7, the opening momentum is already larger than the closing one [2].

Start-up

The functioning of SPPS cannot be guaranteed only by the system´s manufacturer ventilation technology. As many different parties are involved to cooperate, the building owner would be well advised to constitute a start-up team covering all trades, assuming planning and guiding responsibilities. Due to tight time schedules a peak of construction activity is to be observed at the end of the construction period. The final steps to get systems ready and operable are done in a short period of time for many trades. Due to large interconnections of the SPPS with the electrical systems and the building automation, mutual hindrance in the event of simultaneous start-up activity is not uncommon. That is why all resources are to be planned by the start-up team with precise time accuracy. Overlapping start-ups including inefficiencies as well as function testing of uncompleted systems are typical in this construction phase. In order to meet deadlines, it is imperative to plan and to commission sufficient resources in terms of staff and time/money as early as in the run-up to the project. In case of the ECB project, this worked out quite well, thanks to the far-sightedness of the client´s building department along with the project management. As SPPS are to be equipped with safety-related controls to be fully reliable in protective function, the expert for building automation carried out extensive function tests in the framework of interaction testing.

The start-up of large projects is always planned in detail according to standards defined by the Association of German Engineers (VDI) or similar standards. In addition to the start-up this also includes the instruction of the operator and the support of the entire operation throughout the set-up phase up to the final system´s adjustment – across all seasons and operating conditions. In its position as external third party, Canzler plans and accompanies the start-ups across trades in the context of planning or project management mandates. Moreover Canzler also operates as an expert for final inspections across trades.

System Operation

In order to secure the system operation, maintenance, test runs and recurring operation tests of the fire incident matrix functions are carried out by experts. In addition, trainings of the operators as well as the users have to take place on a regular basis.

The guideline VDI 6010, page 3 [3] and the state building codes make it increasingly compulsory to execute full operation tests and active principle tests for safety systems

In conclusion, buildings of a special height and usage are almost always equipped with SPPS. Those can be very successfully planned, constructed and finally put into operation. Knowledge of experienced specialist planners is to be considered in the course of early planning phases. Experienced architects and project managers are supposed to push planning and integration into the building structure and to create space for the SPPS´s technical requirements.

Despite the typical difficulties occurring in large building projects, the commitment and the collaboration of many ECB project parties involved led to a timely deployment of a functioning SPPS in the framework of the construction project. The applied technical solutions are area efficient, cost-effective and guarantee for a secure compliance with the safety objectives. Experience data from the creation and implementation of planning results can help to considerably improve future projects in terms of costs, deadlines and required qualities.

References

[1] DIN EN 12101-6 (09/2005), Smoke and heat control – Specifications for pressure differential systems

[2] VDI-Wärmeatlas (Heating Atlas) 2006, Lac9, Image 28.

[3] VDI 6010, Page 3 (01/2015), Safety systems for building full operation and active principle tests

Pressure relief flaps on the stairway head
as motor controlled blind flaps

Conventional Solution:

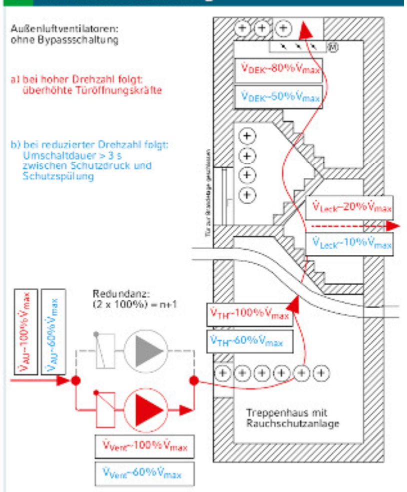
External air fans: without bypass control

a) **Result of high speed: excessive door opening forces**

b) **Result of reduced speed:**
Switching time > *3 s between protection pressure and Protective rinsing*

Staircase with smoke detection system
Protection pressure, layout problems

3 Herkömmliche Lösung



Schutzdruckhaltung, Probleme bei der Auslegung

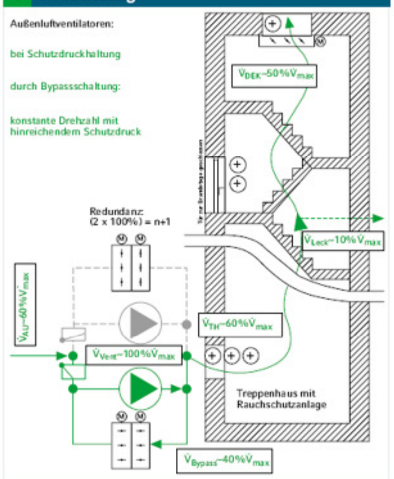
New Solution

External Air fans:

With protection pressure
Via bypass control
Constant speed with sufficient protection pressure

Protection pressure with reduced volume flow in the staircase

4 Neue Lösung



Schutzdruckhaltung mit reduziertem Volumenstrom im Treppenhaus

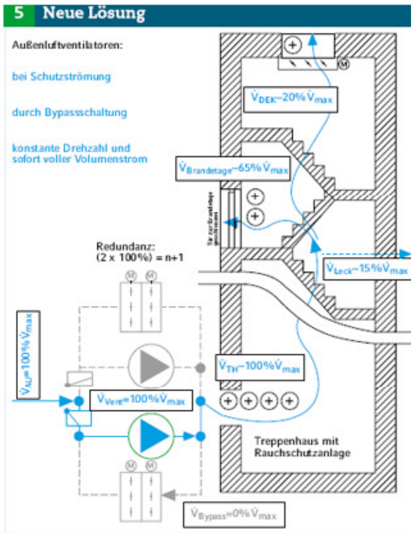
New Solution:

External Air Fans:

With protection flow
Via bypass control
Constant speed with immediate full volume flow

Protection flow with closed bypass

5 Neue Lösung



Schutzströmung mit geschlossenem Bypass

Reflection on Component Failures

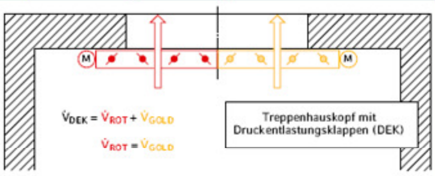
Stairway head with pressure relief flaps

Failure of a flap in any position

RED flap blocked at:
Pressure protection
GOLDEN flap controls
Assessment of function restriction
Protection flow

Example of parallel flow via
Pressure relief flap on the stairway head

6 Betrachtung zum Komponentenausfall



Ausfall einer Klappe in beliebiger Stellung			
	ROTE Klappe blockiert bei:		
	0 - 20°	20 - 70°	70 - 90°
Schutzdruckhaltung	GOLDENE Klappe regelt		
$\dot{V}_{DEK}$ ~ 50% $\dot{V}_{max}$	45 - 90°	20 - 70°	0 - 45°
Bewertung der Funktionseinschränkung	gering	gering	gering
Schutzströmung	GOLDENE Klappe regelt		
$\dot{V}_{DEK}$ ~ 20% $\dot{V}_{max}$	20 - 70°	0 - 30°	0°
Bewertung der Funktionseinschränkung	gering	gering	gering

Beispiel einer Parallelströmung durch Druckentlastungsklappe am Treppenhauskopf