STUVA Tagung vom 25. bis 27. November 2025 in Hamburg

Future Circular Collider CERN – Herausfordernde Lüftung und Kühlung einer außergewöhnlichen unterirdischen Anlage

Future Circular Collider CERN - Challenging Ventilation and Cooling of an exceptional Underground Facility

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Zusammenfassung (Deutsch)
Die Europäische Organisation für Kernforschung (CERN) hat eine Machbarkeitsstudie für einen wesentlich größeren Teilchenbeschleuniger durchgeführt. Dieser Future Circular Collider (FCC) umfasst einen kreisförmigen Tunnel mit einem Umfang von 90,7 km und einer durchschnittlichen Tiefe von 200 m sowie acht Oberflächenstandorte in der Nähe des südlichen Endes des Genfersees. Neben dem Betrieb des Beschleunigers und der Durchführung anspruchsvoller Experimente stellen auch die Belüftung und Kühlung dieser außergewöhnlichen unterirdischen Anlage eine große Herausforderung dar. Diese Systeme müssen in verschiedenen Betriebsmodi effektiv arbeiten. Dabei müssen die anspruchsvollen Kriterien, die zum Teil mit der radioaktiven Umgebung zusammenhängen, im Beschleunigertunnel und in einem umfangreichen System von angrenzenden Kavernen, Tunneln und Schächten erfüllt werden. Der vorliegende Beitrag befasst sich mit den Herausforderungen, die bei der derzeitigen Auslegung der Belüftung und Kühlung bestehen. Darüber hinaus werden die Spezifikationen der Lüftungs- und Kühlsysteme vorgestellt und Optimierungsmöglichkeiten aufgezeigt.

Summary (English)
The European Organization for Nuclear Research (CERN) conducted a feasibility study for a substantially increased circular collider. This Future Circular Collider (FCC) includes a circular tunnel with a circumference of 90.7 km, at an average depth of 200 m and eight surface sites in the vicinity of the southern end of Lake Geneva. Beside the operation of the accelerator and the execution of sophisticated experiments, the ventilation and cooling of this exceptional underground facility exhibit great challenges. These systems must perform effectively during several operation modes. Herewith the demanding criteria partly involving radioactive environment must be fulfilled in the collider tunnel and in an extensive system of adjacent caverns, tunnels and shafts. The present paper focuses on the challenges found during the current ventilation and cooling design. In addition, the specifications of the ventilation and cooling systems are presented along with envisaged optimisations.

1 Introduction

The work presented in this document is part of the feasibility studies conducted in the framework of the FCC design. It contains information based on reports submitted from design team of HBI Haerter and AFRY to CERN, together with information from the CERN baseline studies [1].

The reports about the feasibility study of FCC was published on March 2025 and can be found in [2].

1.1 Geometry and situation of the FCC tunnel

The configuration of underground facilities foreseen for FCC is shown in Figure 1. The FCC tunnel (in light blue) is a circular tunnel with a total length of about 90.7 km. It is organized in 8 sectors with a length of approx. 11'300 m each. The sectors are delimited by access points (A, B, D, F, G, H, J and L) consisting of surface buildings, service shafts, service caverns, access tunnels and experimental caverns (at points A, D, G, J).

The typical cross section of the accelerator tunnel is shown in Figure 2. This cross section corresponds to the baseline design and includes an air supply duct in the invert.

The unequipped, circular tunnel has an inner diameter of 5.5 m. Considering all the equipment, the remaining free cross section is approximately 15.2 m^2. At the tunnel crown, an emergency extraction duct (cross section 1.9 m^2) is formed by a plate (i.e., false ceiling) closing a circular tunnel segment.

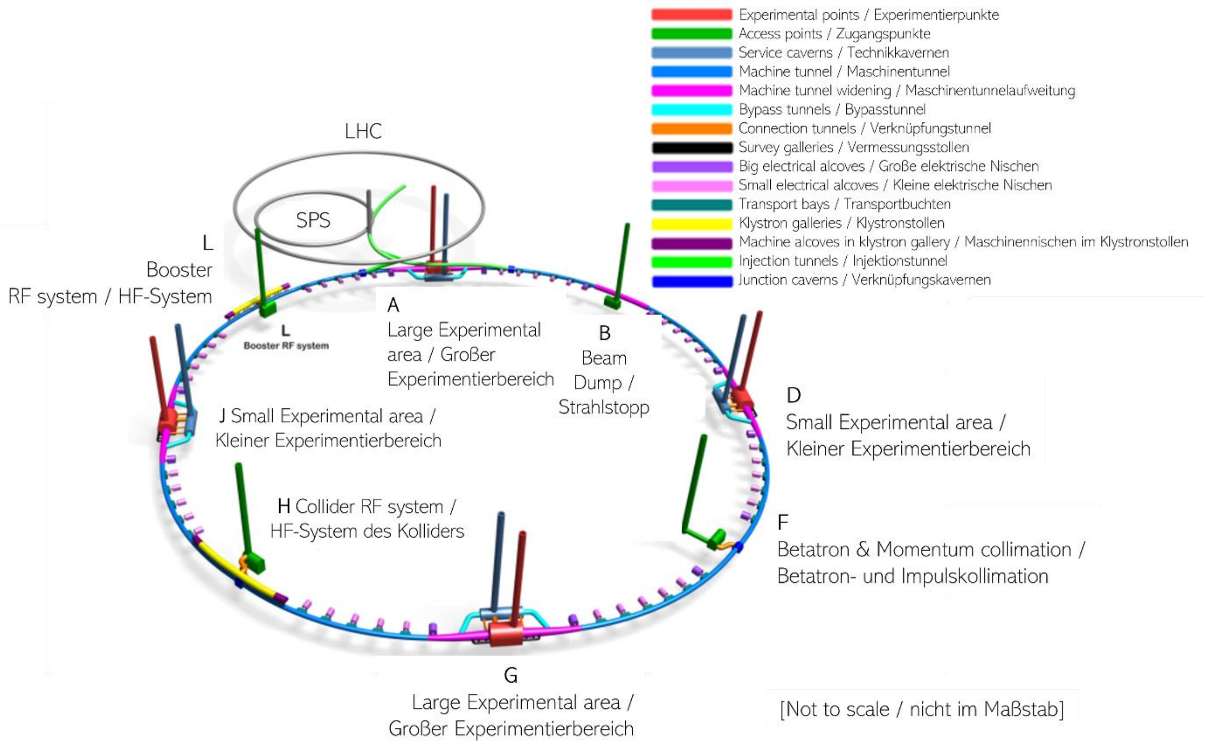

Figure 1: FCC underground structure layout / Layout der unterirdischen Anlage von FCC

A division of the tunnel sectors in 440 m long compartments is foreseen for fire protection purposes, with a total of 26 compartments per sector. The compartments are delimited by fixed fireproof panels and automatic fire doors to control the propagation of smoke in case of fire.

During normal operation, all doors are open. In case of a fire, the doors of the fire affected as well as of the adjacent compartments are closed.

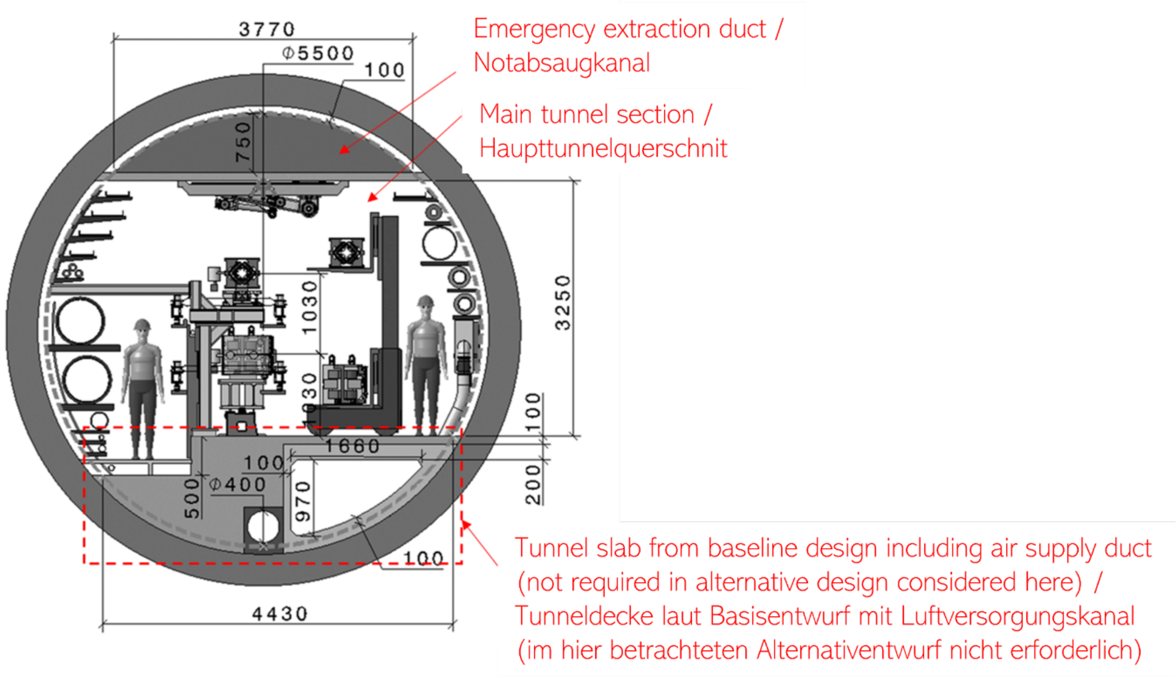

Figure 2: Cross section of the FCC accelerator tunnel / Querschnitt des Teilchenbeschleunigertunnels von FCC

2 Baseline ventilation and cooling system of the main tunnel

2.1 Ventilation system

2.1.1 Description of the baseline ventilation system

Each sector is treated individually in terms of tunnel ventilation. A sketch of the ventilation concept of the sector is shown in Figure 3. The ventilation components for air treatment (Air Handling Units AHUs and smoke extraction fans) are located at ground level (i.e., in surface buildings), whereas local cooling devices, air ducts, dampers and Variable Air Volume (VAV) units for air distribution are underground.

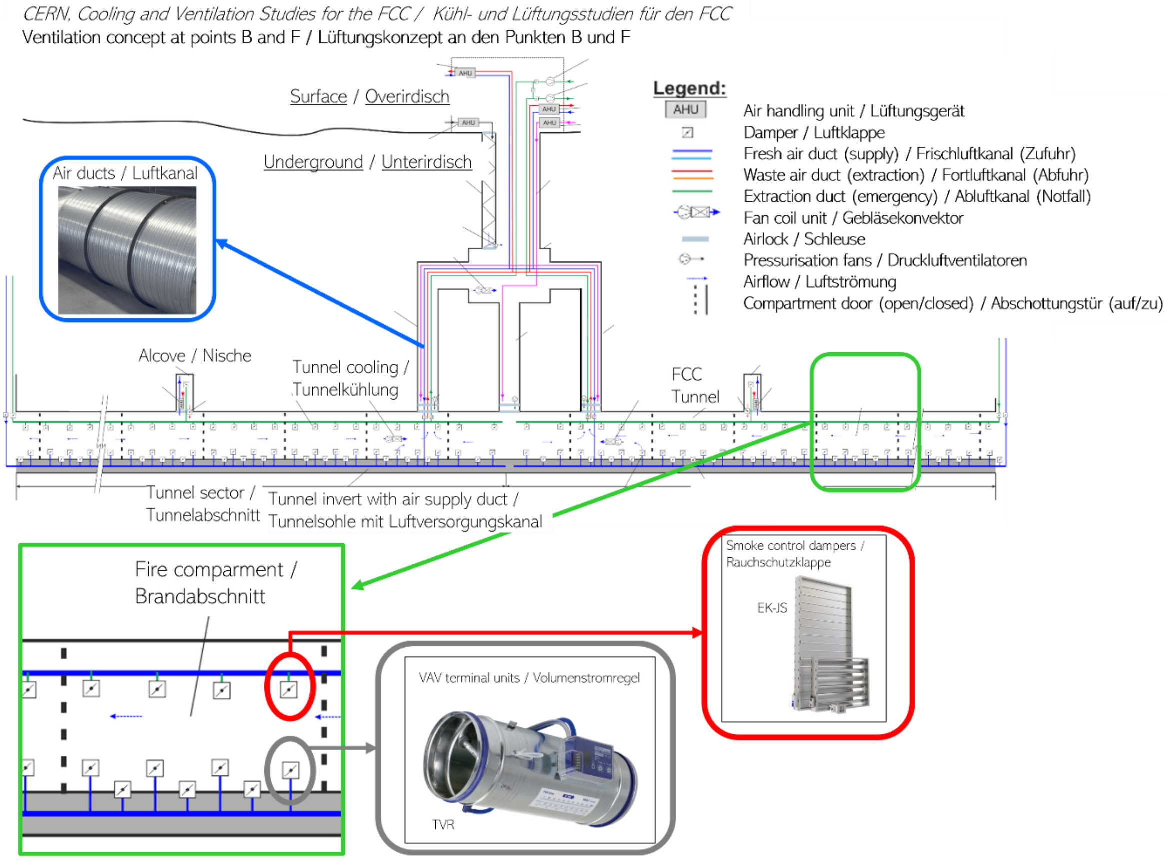

Figure 3: Scheme of the tunnel ventilation system proposed for FCC (baseline design from CERN) / Schema des vorgeschlagenen Tunnellüftungssystems (Basisentwurf von CERN)

2.1.2 Modes of operation of the tunnel ventilation system

Depending on the running activity in FCC, the following operation modes are defined for the tunnel ventilation system:

1. Run mode: ventilation during the operation of the particle accelerator. Air is supplied from AHU plants being at ground level and it is transversally distributed from the VAV units underground (Figure 4).
2. Flushing mode: ventilation for a complete renewal of the tunnel air when the particle accelerator is stopped and before access of people. In this mode, air, at higher flow rate than in run mode, is supplied longitudinally to the tunnel (Figure 5).
3. Access mode: ventilation when people are in the tunnel. The same concept as in run mode is employed (Figure 4).
4. Emergency mode: ventilation in case of a fire in the tunnel. The compartments affected by the fire are isolated (i.e., fire doors of affected and neighboring compartments closed), air is distributed from VAV units, but with a different setpoint than during run/access mode, and smoke is extracted from the ceiling extraction duct by opening the smoke dampers of the affected compartments (Figure 6).

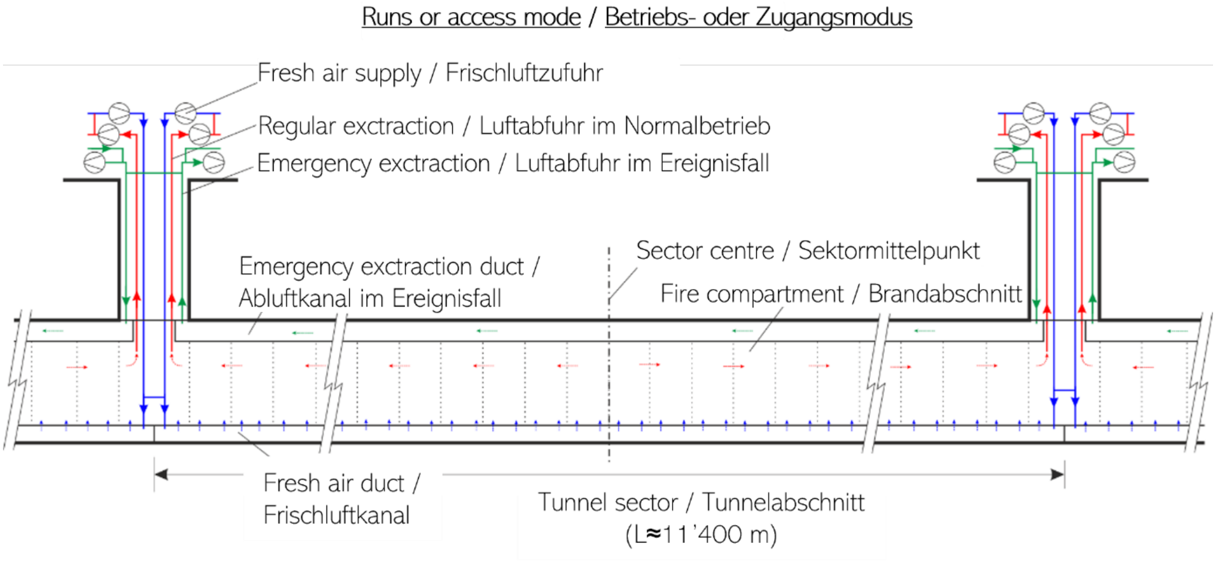

Figure 4: Sketch of the tunnel ventilation system (one tunnel sector) in run and access mode / Skizze des Tunnellüftungssystems (ein Tunnelabschnitt) im Betriebs- und Zugangsmodus

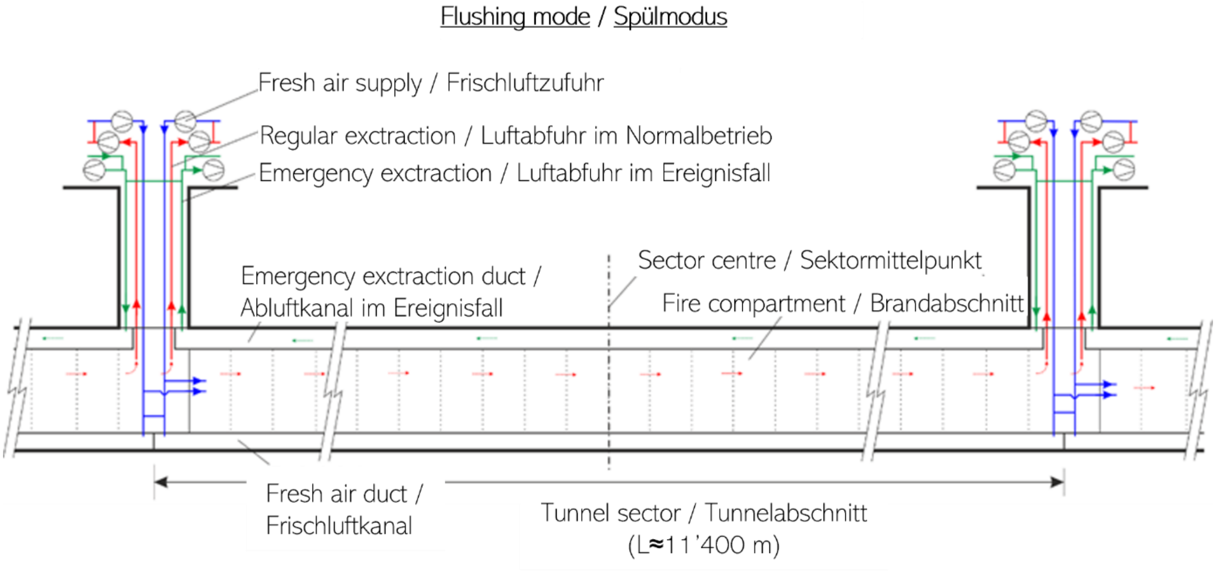

Figure 5: Sketch of the tunnel ventilation system (one tunnel sector) in flushing mode / Skizze des Tunnellüftungssystems (ein Tunnelabschnitt) im Spülmodus

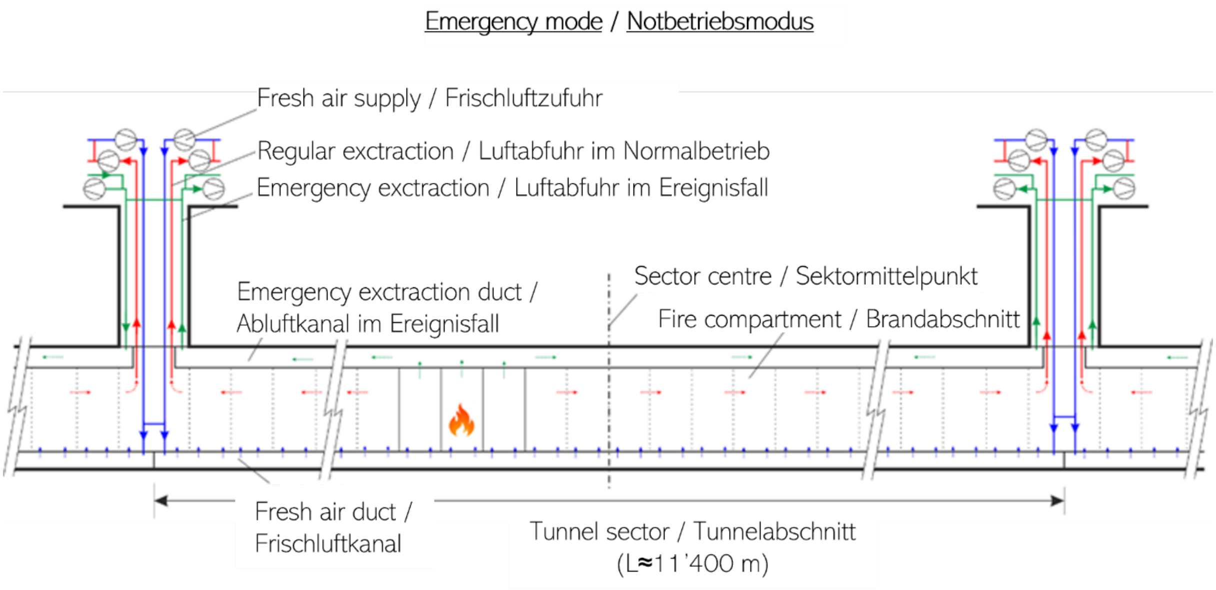

Figure 6: Sketch of the tunnel ventilation system (one tunnel sector) in emergency mode / Skizze des Tunnellüftungssystems (ein Tunnelabschnitt) im Notbetriebsmodus

2.2 Cooling system

2.2.1 Description of the cooling system

The cooling system is based on two primary and one secondary cooling water systems. The primary cooling water systems provide the heat sinks for all heat sources. The secondary one cools the various components of the tunnel. The communication point between primary and secondary cooling systems consists of heat exchangers.

The baseline layout for the primary cooling consists of a set of field erected, open, wet cooling towers (Figure 7 and Figure 8). For each location there is a set of cooling towers. Each system comprises the necessary number of cells for removing the heat at worst case conditions plus one cell spare capacity. A proposal is that cooling towers are made of FRP (Fiber Reinforced Plastics), which are cost competitive to concrete, even if they need to be replaced once during the lifetime of FCC.

The secondary cooling system, cooled by the cooling tower water by means of heat exchangers, is shown in Figure 9. It is filled with pure demineralized water, and it cools main heat sources (components of the accelerator) that have wetted copper surfaces.

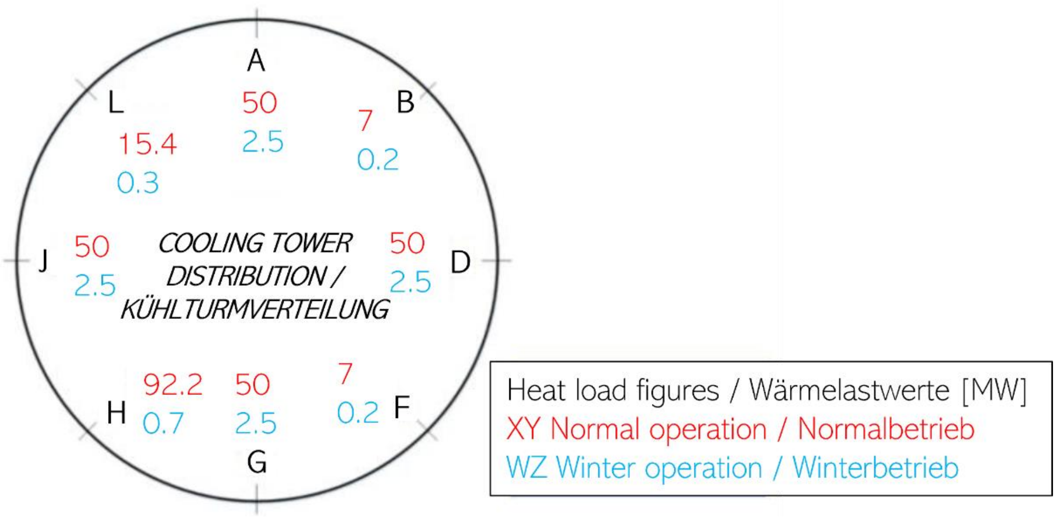

Figure 7: Distribution of summer and winter heat loads (MW) to be managed by the cooling towers of the primary cooling system / Verteilung der sommerlichen und winterlichen Wärmelasten (MW), die von den Kühltürmen des primären Kühlsystems abzuführen sind

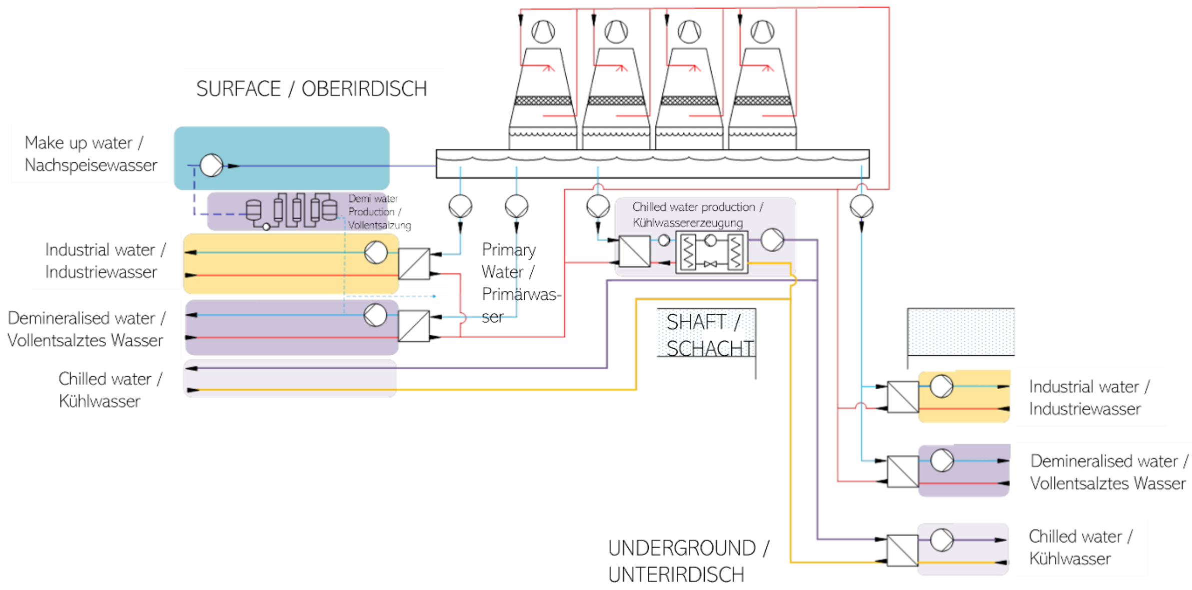

Figure 8: Scheme of the cooling tower cooling system / Schematische Darstellung des aus Kühltürmen bestehenden Kühlsystems

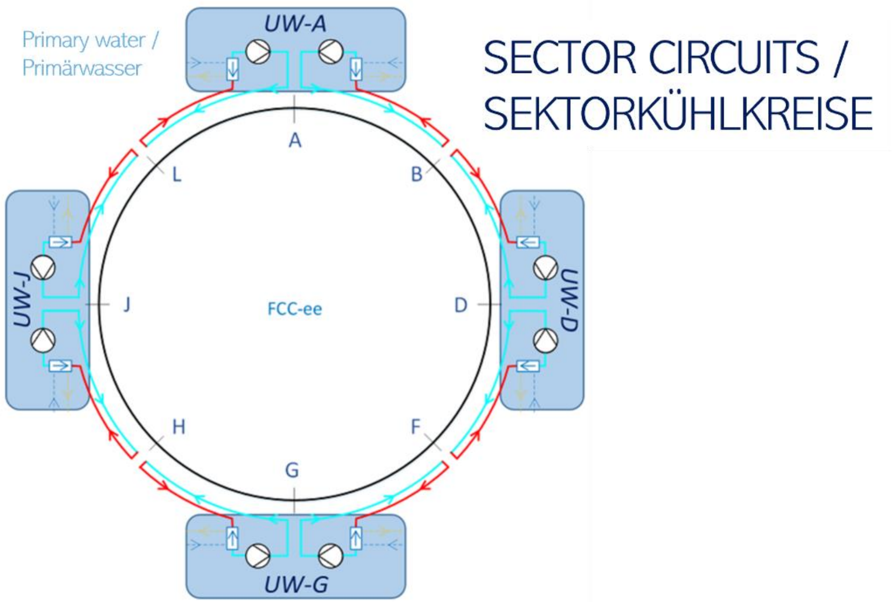

Figure 9: Schematic of the demineralized water cooling of the sectors in the underground, and interface with the primary cooling system / Schema der Kühlung der Untergrundsektoren mit VE-Wasser und deren Verbindung zum Primärkühlsystem

2.2.2 Energy and cooling requirements for the ventilation system

The air handling units treat outside or recycled air that is supplied into the tunnel. They are located at ground level and are water cooled. The highest estimated cooling power demand amounts to about 6.93 MW for dehumidifying the air of the tunnel ring, for ensuring a maximum dew point of 12 °C. The inlet and outlet chilled water temperature is 6 °C and 12 °C, respectively.

The fan coils are also water cooled. They are located inside the tunnel and have the role of controlling the temperature of the air inside the tunnel, absorbing the power released by the equipment. The highest power demand of the tunnel ring amounts to about 5 MW. The inlet and outlet chilled water temperature is 9 °C and 15 °C, respectively.

3 Challenges

3.1 Ventilation system

A big challenge is related to the control of the air supply distribution along the accelerator tunnel because of the variable setpoints of each operation mode. In particular, it requires the individual setting of many dampers (originally, up to 210 per tunnel sector), which are all connected to the same, 11 km long supply duct (thus interdependent). Moreover, such dampers will have to cope with a broad range of pressure-flow conditions.

Another significative challenge is related to the ionizing radiation levels, which must be accounted for in the design of equipment installed in the tunnel. The expected values in the order of 100 kGy to 1 MGy are much higher than the specifications that can be found for most of the commercial-off-the-shelf components (typical resistances are in the range of 50-1’000 Gy, see [3] and [4]). Reductions in the lifetime of the equipment in the tunnel, as well as periodical replacements during the lifetime of FCC, are to be taken into account, unless custom design products with appropriate radiation are developed.

3.2 Cooling system

Big challenges are related to the reduction of the following aspects:

- water consumption, as most of the heat is dissipated by evaporating water
- wastewater production at surface cooling towers
- energy consumption due to the circuit pumps, fans and water treatment
- visual impact of plumes

4 Alternative design to tackle the challenges

4.1 Tunnel ventilation system

The alternative design of the tunnel ventilation system aims at its simplifications. Particularly, longitudinal ventilation is applied (punctual delivery of supply flow at the beginning of the tunnel sectors) instead of the distributed air supply from the slab duct. This allows removing the VAV units and the slab duct, thus releasing tunnel space for other systems, reducing costs and simplifying ventilation control (e.g., no individual damper regulation during run and access mode) at the same time. The corresponding concepts of run, access and flushing modes are unified to one general scheme, as shown in Figure 5. The new emergency mode concept is illustrated in Figure 10. Unlike the baseline design, the alternative requires dampers in the separating doors of the compartments, since the flow must reach the compartments affected by the fire, upon closure of the compartment doors, from the tunnel itself and not from the slab duct. This system further ensures a pressure cascade towards the affected compartments with respect to the rest of the tunnel. Thus, the smoke spread to other compartments is prevented. A similar depression of the affected compartments can be accomplished in the baseline design, but involves a more complicated regulation of the VAV units based on pressure and volumetric flow.

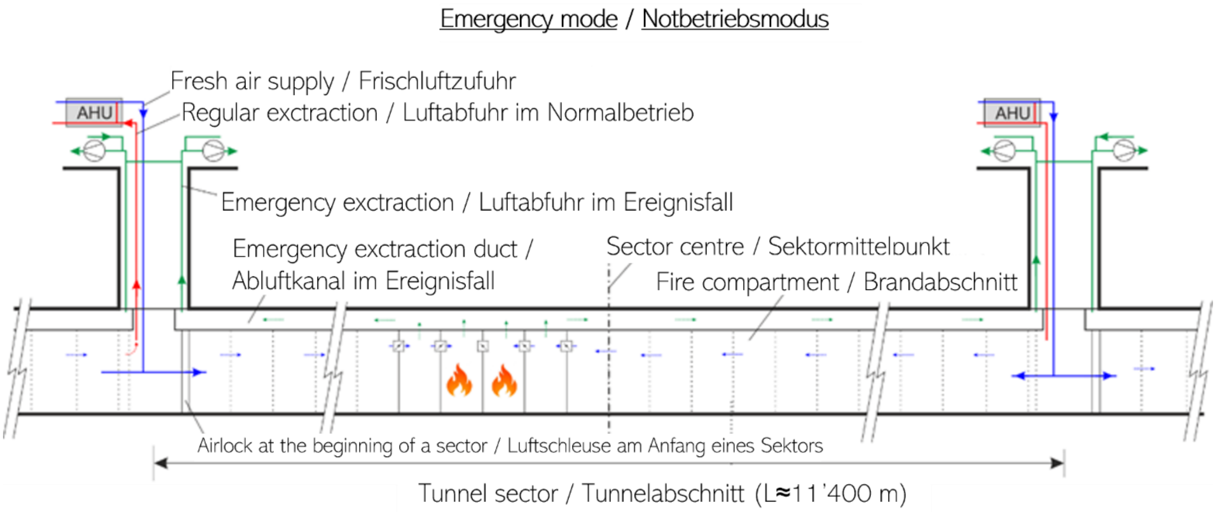

Figure 10: Sketch of the alternative tunnel ventilation system (one tunnel sector) in emergency mode / Skizze des alternativen Tunnellüftungssystems (ein Tunnelabschnitt) im Notbetriebsmodus

4.2 Cooling system

The wet cooling towers of the baseline design might consume a significant amount of water and show a visible plume, which might be an obstacle for receiving construction permits. The proposed alternative consists in the replacement of the wet cooling tower by a hybrid cooling tower to reduce water consumption and wastewater production. Hybrid cooling combines wet and dry cooling. According to this concept, a part of the warm water passes through an air water heat exchanger that pre-cools the water depending on ambient temperature. This warm water is mixed with the humid air after the wet cooling part. The hybrid cooling towers transfer 15% of the heat (optimum value) to the atmosphere with the dry section at summer design conditions, thus reducing water consumption by 20% in average thanks to the optimized winter operation, but without compromising the cooling efficiency. The wet cooling part ensures cooling efficiency and mitigates the impact of high ambient temperatures by evaporating water. With this system, during the low winter heat load (about 17 weeks per year), it is possible to operate one cell only and to shut down half of the cooling tower system for cleaning. Moreover, visible plumes of the cooling towers are avoided in summer and minimized in winter.

5 Conclusions

The FCC is a project even more ambitious than the current LHC and the demonstration of its feasibility is crucial for the process of getting the approval to prosecute to following stages. Among the technological challenges that FCC aims to overcome, this paper presented the ones related to the ventilation and cooling systems. Together with the current baseline design of the two systems, alternatives were discussed for increasing the reliability, optimizing the functionality and decreasing the costs of the system.
Herewith feasible concepts for cooling and ventilation of this extraordinary underground facility have been found and confirmed. Within the next project stages and upon the results of this study, decisions regarding the final concepts shall be taken and a further and detailed design of these systems is required.

6 Literaturverzeichnis

[1] CERN, HBI, AFRY, “Cooling and ventilation studies for the Future Circular Collider Study”, multiple reports, 2023-2024

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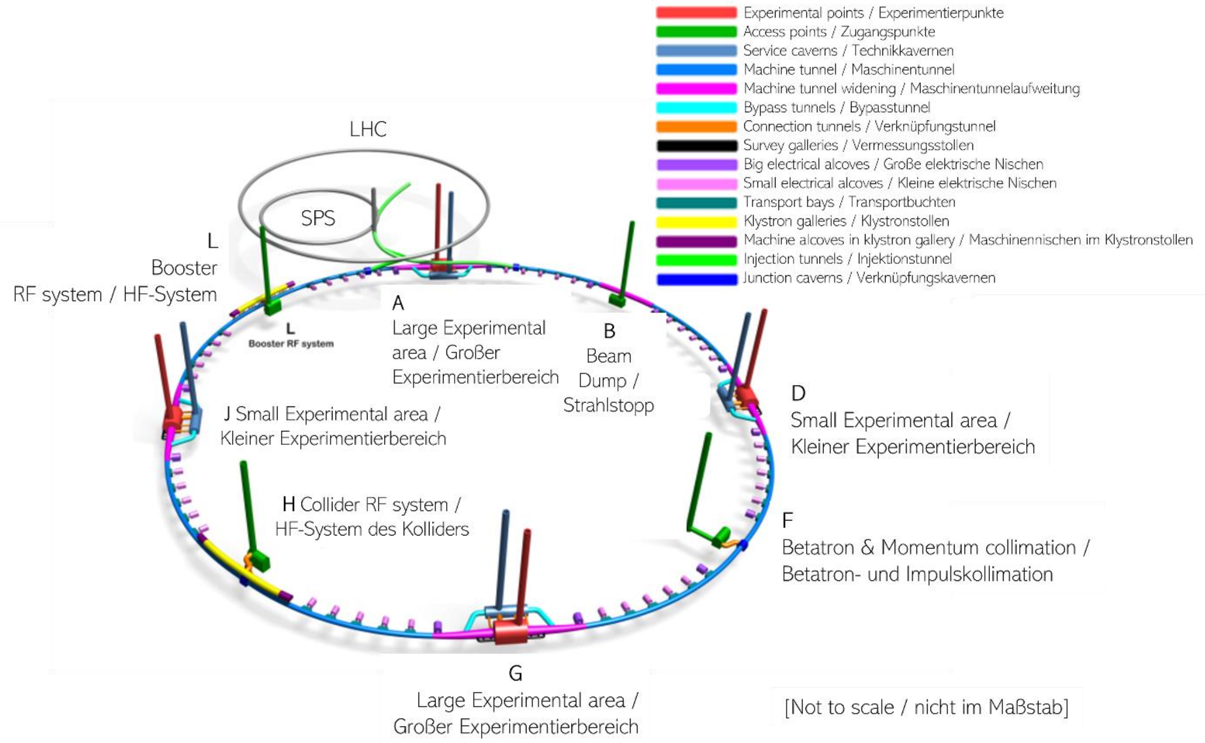
[3] B. Todd and S. Uznanski, CERN, “Radiation Risks and Mitigation in Electronic Systems”, Proceedings of the CAS-CERN Accelerator School: Power Converters, Baden, Switzerland, 7-14 May 2014

[4] CERN, “CV_Technical_Prescription_on_Ventilation_installations_1271864_ v.6.0.pdf”

7 Abbildungsverzeichnis



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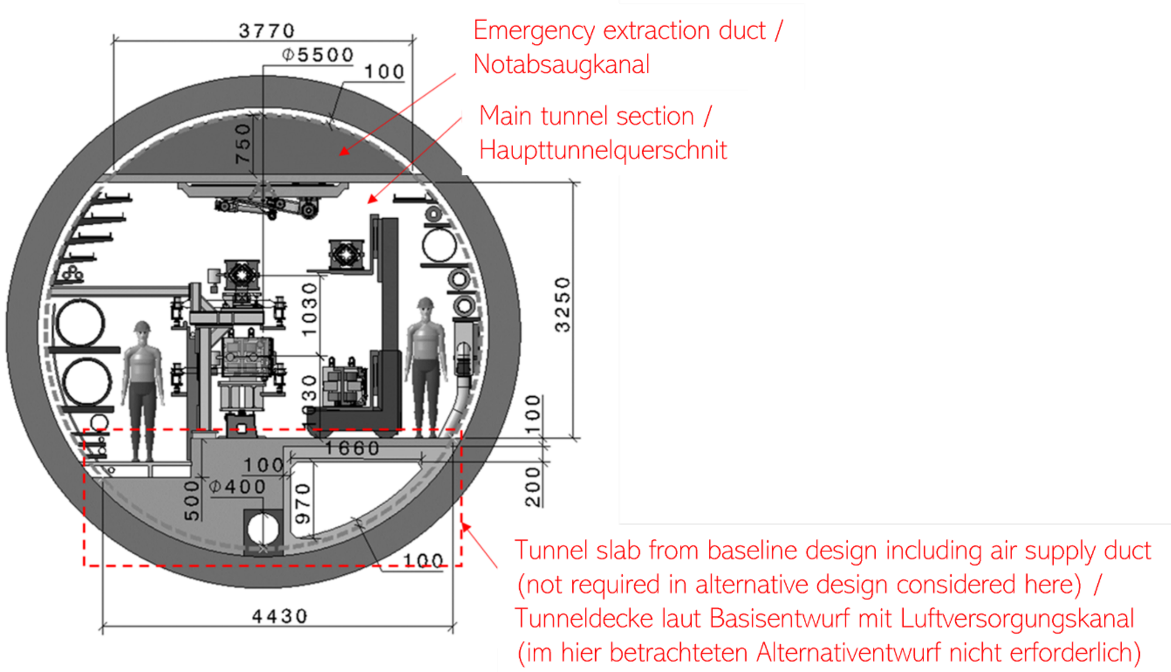

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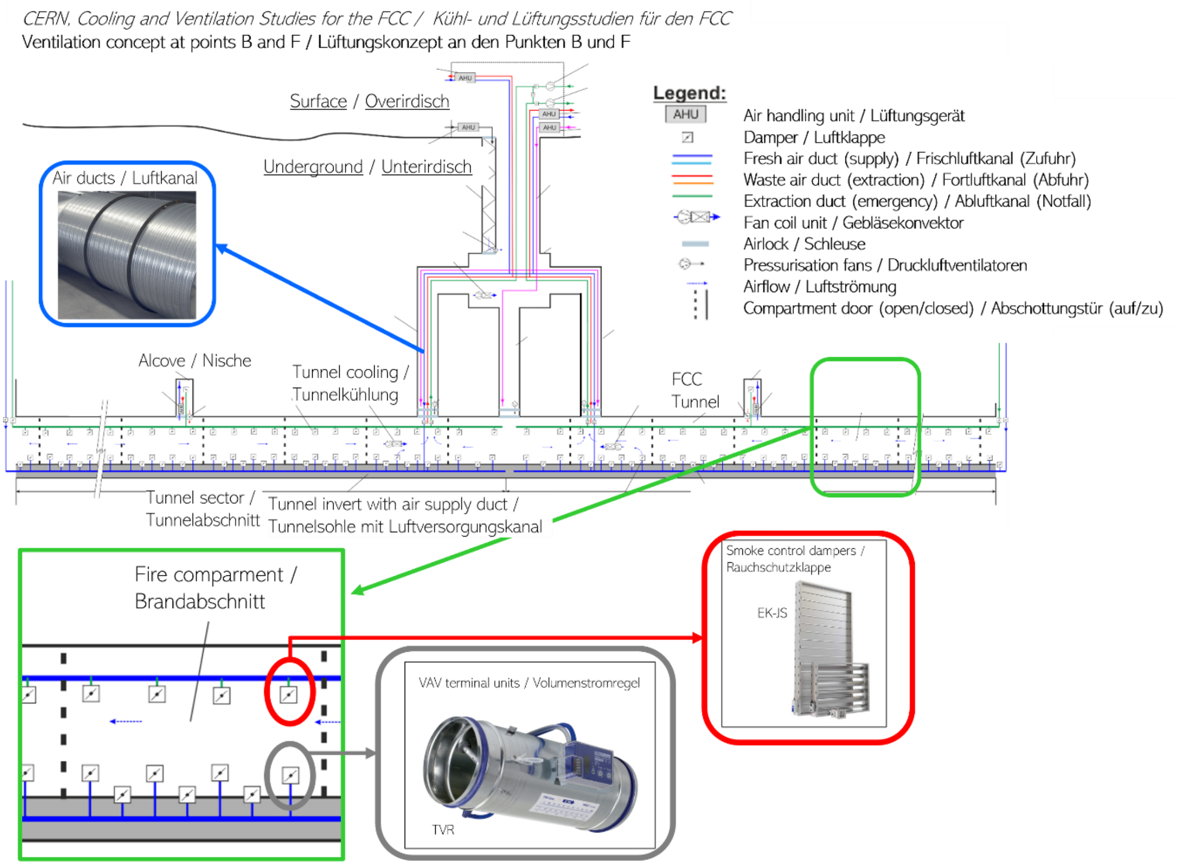

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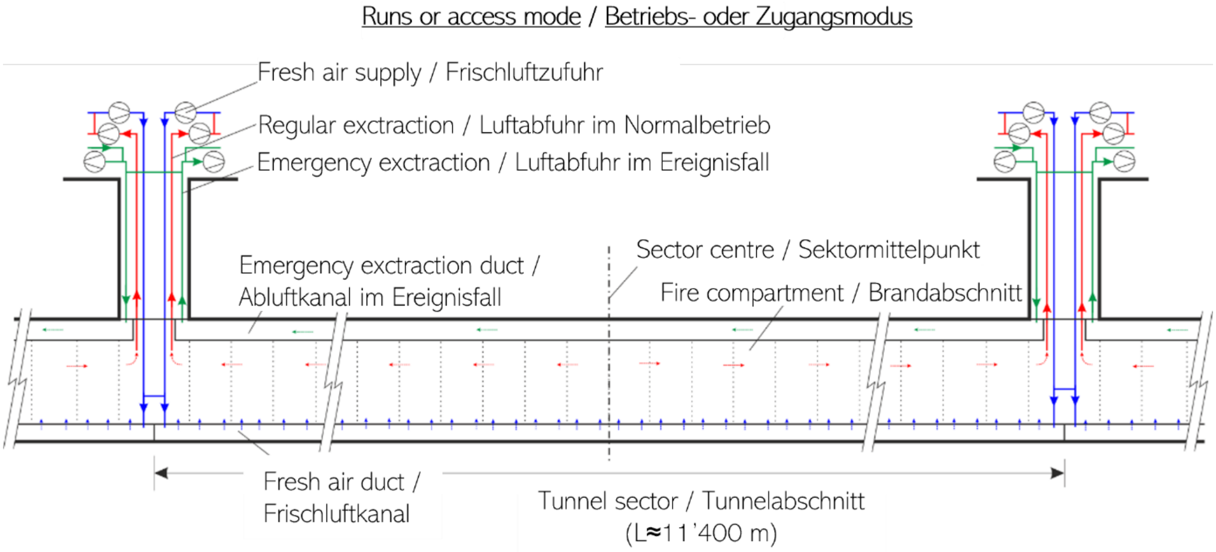

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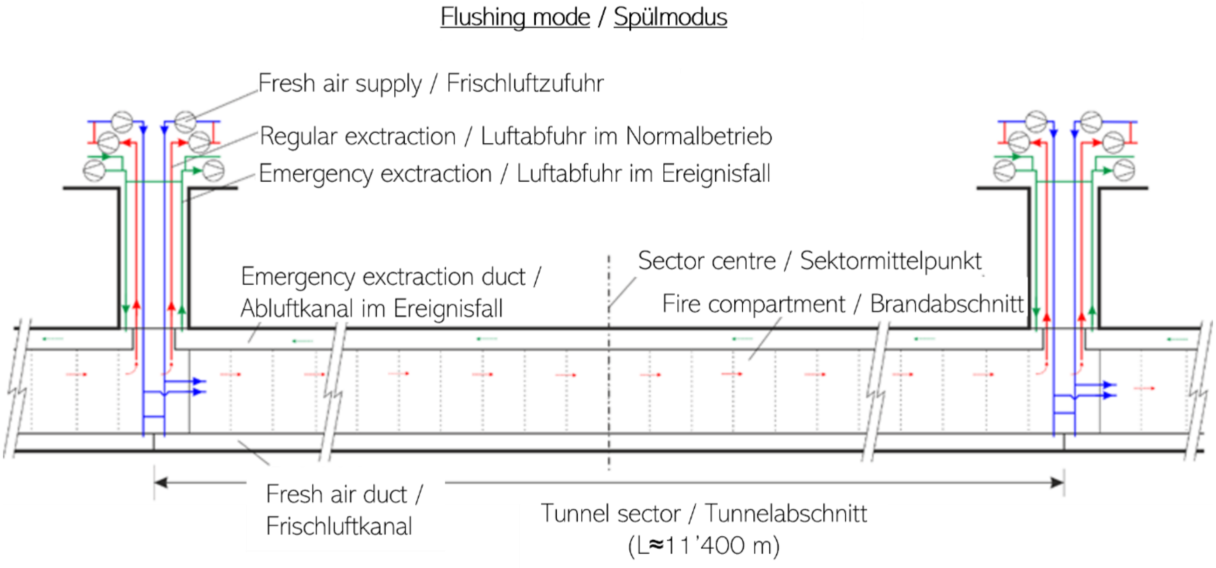

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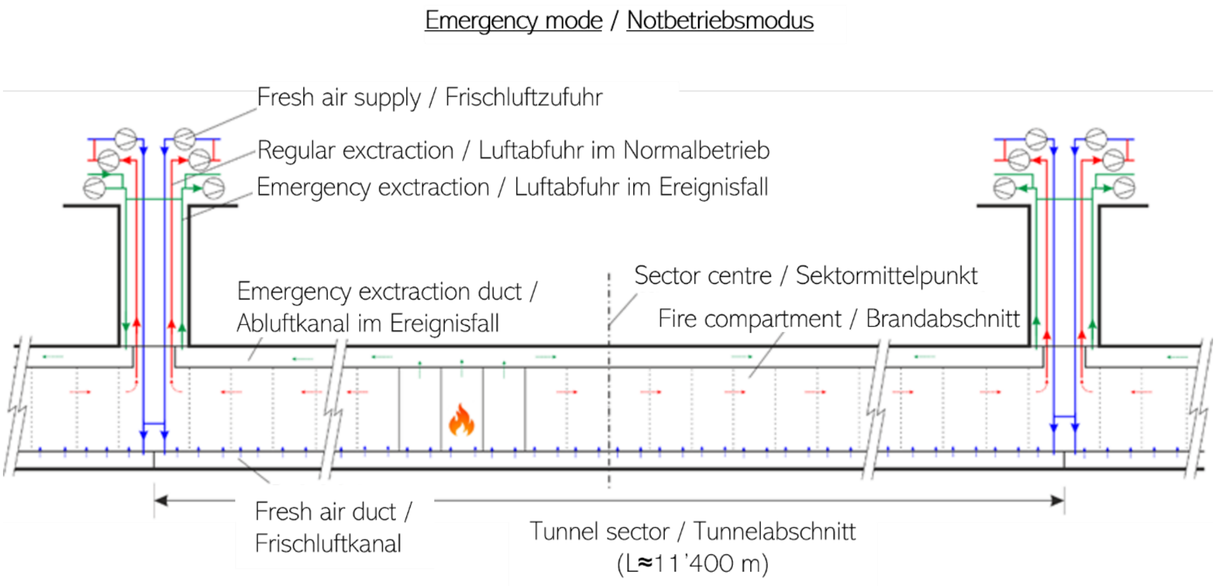

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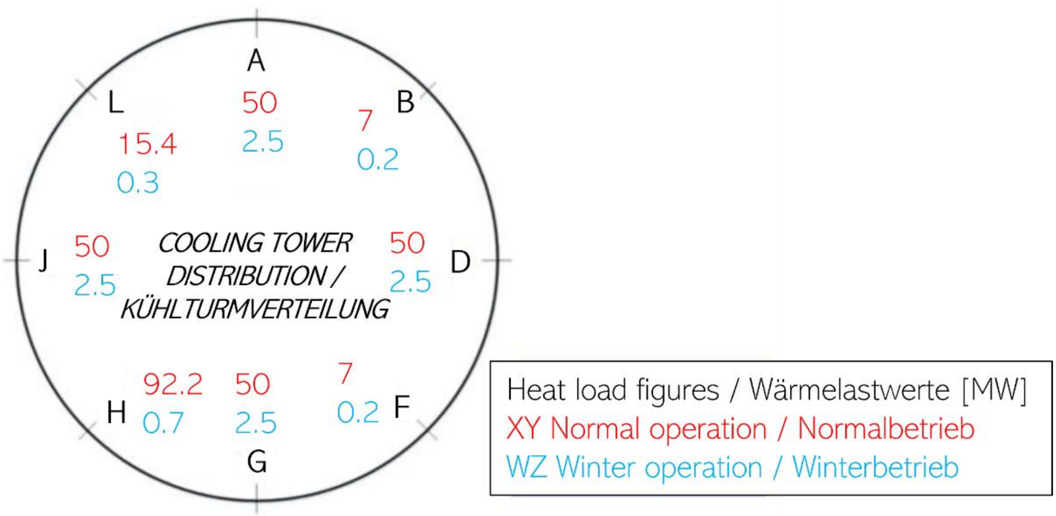

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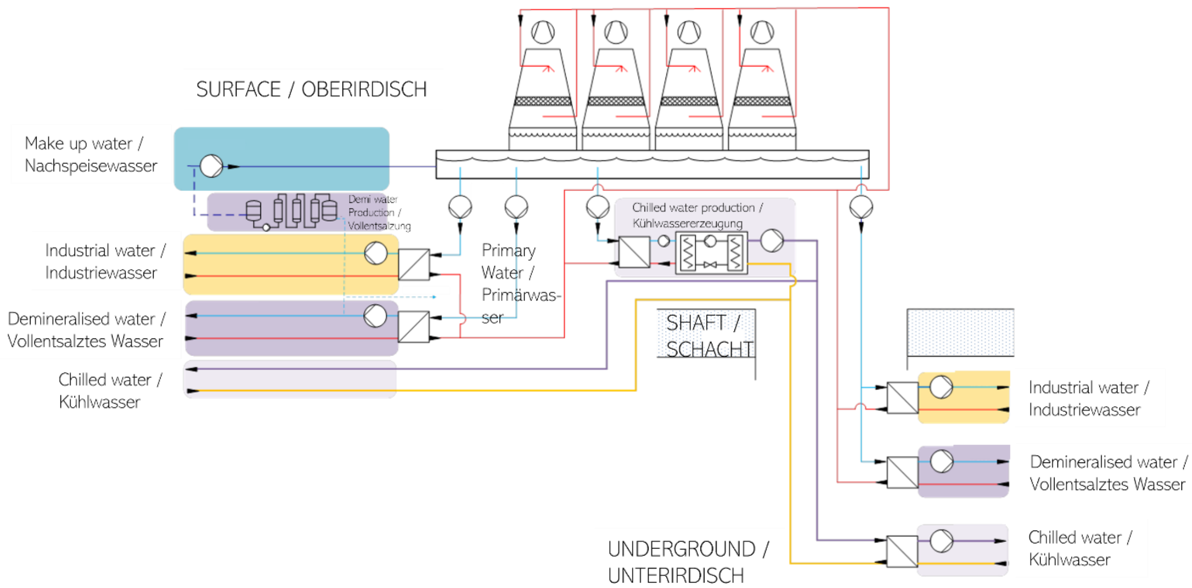

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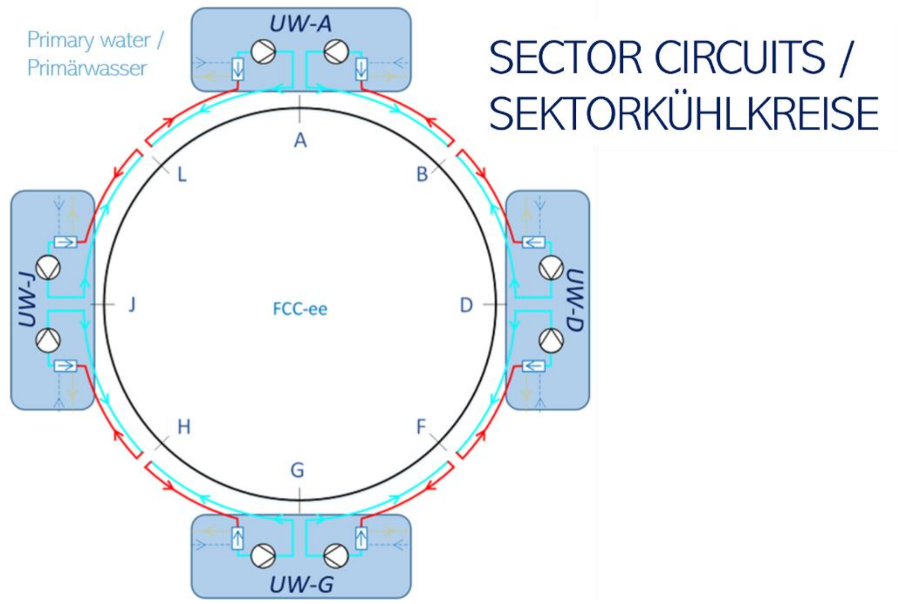

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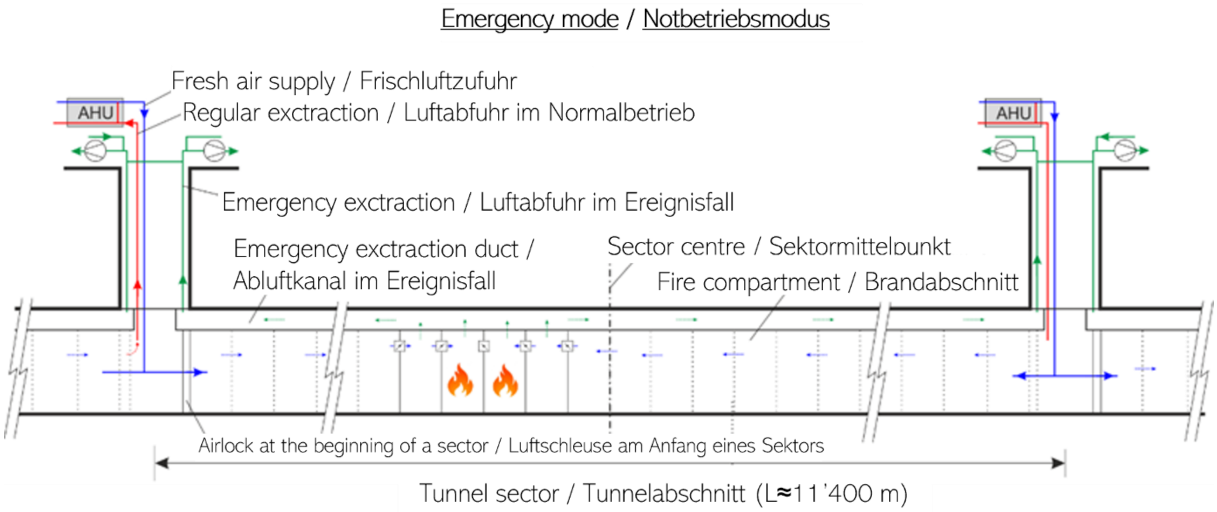

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