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Chapter 23

The HL-LHC Technical Infrastructure

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The upgrade in luminosity of the LHC requires large and new technical infrastructures like civil engineering, electrical distribution, cooling, ventilation, access system, alarm system, transport, and operational safety system. This chapter describes the new technical infrastructure including layout, performance requirements and architecture as well as the main technical challenges.

1. Introduction

The HL-LHC technical infrastructure includes the civil engineering, the electrical distribution, the cooling & ventilation, the access & alarm system, the technical monitoring, the transport infrastructure, and the operational safety.

2. Civil Engineering

In terms of civil engineering, the needs of the HL-LHC consist principally of access shafts from the surface to the underground areas together with various underground caverns and galleries. Buildings are required on the surface for housing technical infrastructures such as compressors, cooling equipment, ventilation equipment, electrical equipment, helium refrigerators and helium and nitrogen storages. The HL-LHC construction work are located in the two-existing large-experimental sites, Point 1 (P1) for the ATLAS experiment, located in Switzerland, and Point 5 (P5) for the CMS experiment, located in

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France, and include underground and surface works at both points. At both locations, some of the new structures are located close to existing LHC infrastructure, hence, special protective measures must be taken to minimize impact on the operation of the LHC and also on the LHC infrastructure itself. For this reason, the main excavation work, which causes vibrations detrimental to the LHC luminosity, have been performed over 2 years (2019 and 2020) during the ca. 2.5-year long LS2 shutdown. The total duration of the civil engineering work extends for about 5 years starting in 2018.

2.1. *Underground civil engineering*

The underground civil-engineering at each point consists of a vertical shaft (PM, 10-m diameter, 60-m height), a service cavern (US & UW, 16-m diameter, 50-m length), a power converter gallery (UR, 6-m diameter, 300-m length), service galleries (UA & UL, 4 to 6-m diameter, 50-m length), safety galleries (UPR) and vertical linkage cores (1-m diameter, 7-m length) to the existing LHC tunnel. The civil engineering work includes the excavation, the primary concrete, the final lining and the main steel structures. Figure 1 shows a typical underground layout. Safety galleries allow the safe evacuation of personnel in case of underground fire or helium spill. These new underground structures have a useful volume of 25’000 m^3 per Point.

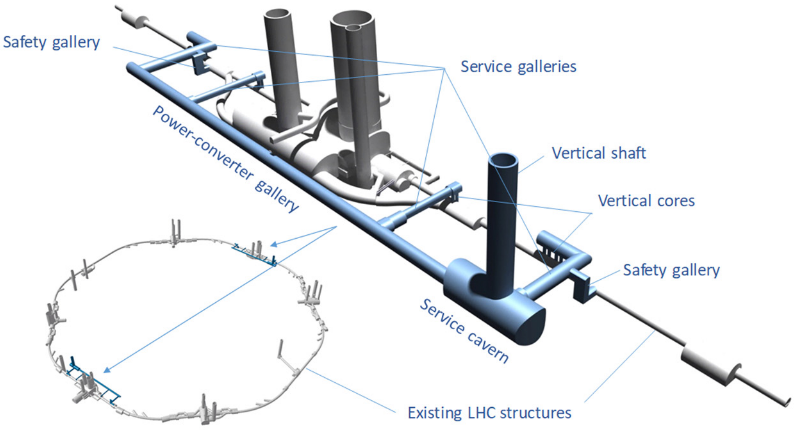

Fig. 1. Typical HL-LHC underground civil engineering structures at Point 1 and Point 5.

2.2. *Surface buildings*

A cluster of three buildings and two standalone buildings are required at P1 and P5. Figures 2 and 3 show the corresponding layouts. These five new buildings are a combination of steel and concrete structures, interconnected with technical galleries. The buildings represent an additional floor area of 6200 m^2. The head-shaft building (SD) covers the underground access shaft and integrates the main cold box of the new helium refrigerator. The ventilation building (SU) mainly contains the equipment needed for the heating, ventilation, air conditioning and smoke extraction of the underground infrastructure. This reinforced-concrete and noise-insulated building is split into two sections that house compressors and air handling units, respectively. The electrical building (SE) contains three rooms dedicated to switchgear, protection relays, switchboards, and uninterruptible power supplies (UPS). The cooling-tower building (SF) is constructed in reinforced concrete to guarantee its noise insulation. This building is split into two areas, one for the three cooling towers which extracts the heat from the primary water circuits, and one for the pump room. Finally, the cryogenic-compressor building (SHM),

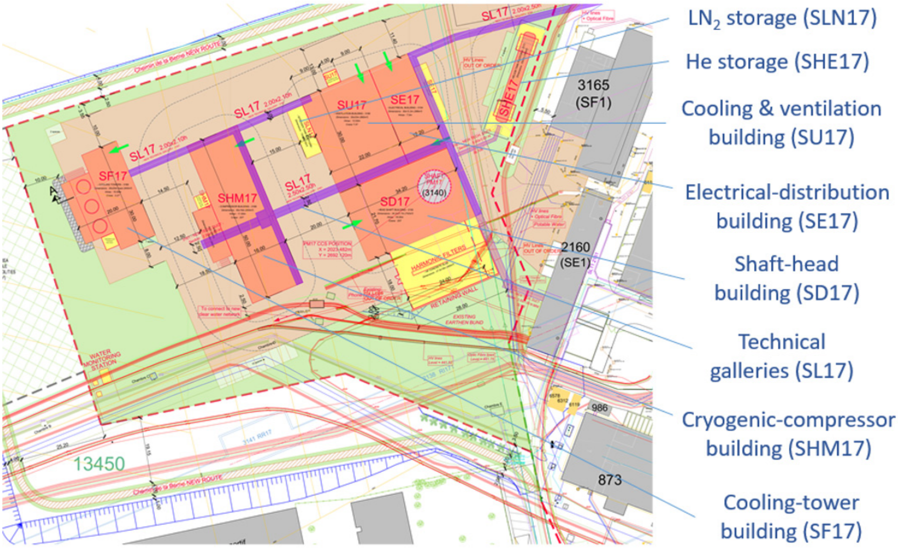

Fig. 2. HL-LHC building layout at Point 1.

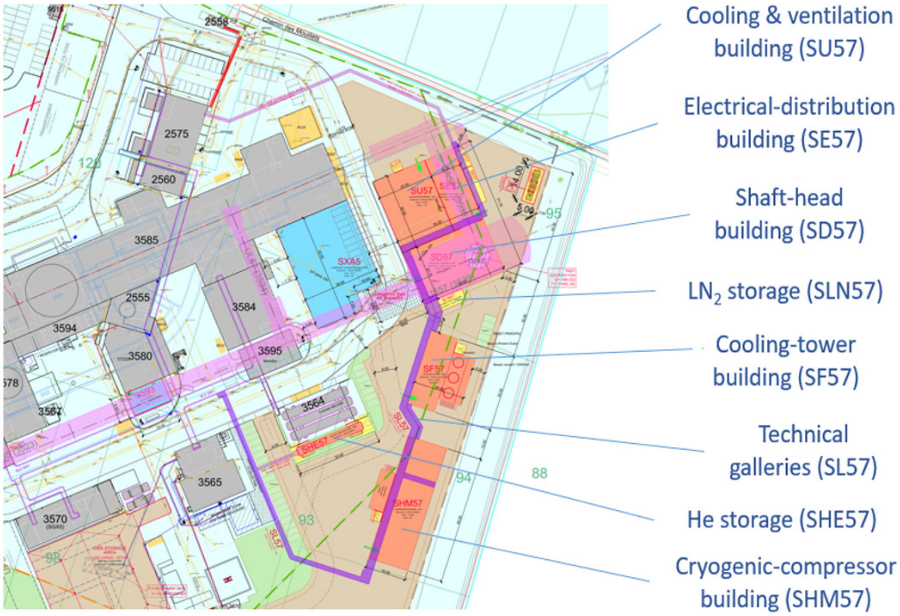

Fig. 3. HL-LHC building layout at Point 5.

also in reinforced concrete and noise-insulated, houses the cycle compressors of the new helium refrigerators.

Additional platforms for helium and nitrogen storage tanks, for harmonic filters and electrical transformers complete the layout. Environmental considerations require external drainage and oil separation systems protecting any sensitive water aquifers at the sites. The additional noise impact of the new buildings on the surrounding population is also minimized.

3. Electrical Distribution

The existing CERN electrical network is shown in Figure 4. The present strategy is to transmit electrical power to each important technical site using 66-kV independent transmission lines. The Point 5 is presently not following this strategy as this site is supplied directly from the Point 6 via an 18-kV line having a rating of 15 MVA. This rating is not adequate with respect to the new needs corresponding to 12 MVA for HL-LHC and 5 MVA for the CMS

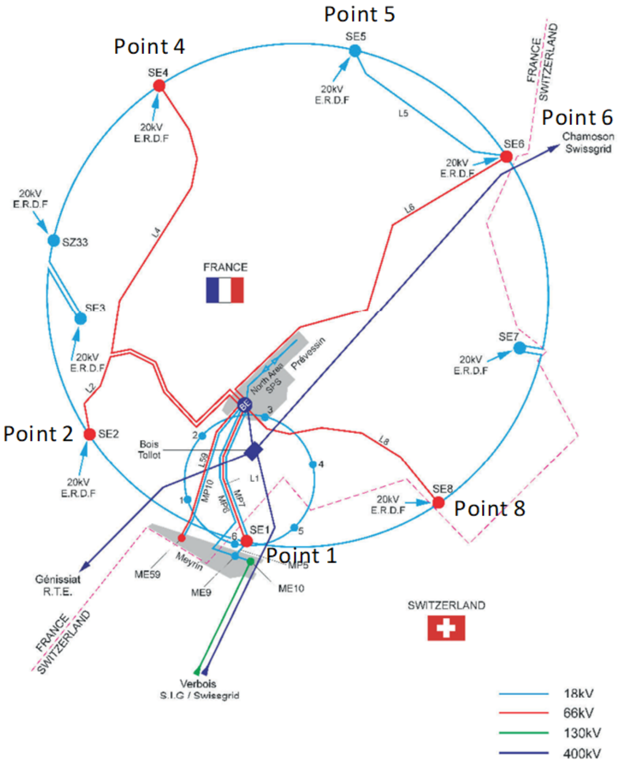

Fig. 4. Existing CERN electrical network.

experiment, which must be added to the 5 MVA presently existing. Consequently, the electrical network must be consolidated with a new 66-kV transmission line directly feeding the Point 5. On site, a new 38-MVA electrical transformer and new harmonic filters allow the distribution of 18-kV high-quality power.

At Point 1, the existing power consumption is 41 MVA. Additional loads of 11 MVA for the HL-LHC machine and 2 MVA for the ATLAS experiment bring the total electrical consumption to 54 MVA. This new power can be delivered by the existing electrical sub-station and only harmonic filters must be added for HL-LHC.

On site, electrical transformers producing 3.3-kV and 400-V networks are dry-type and therefore do not create problems in relation to oil pollution. In terms of electrical distribution, four types of electrical networks are available for users: general services, machine network, secured network (backed-up by diesel generators) and uninterruptible power supply network (UPS). High current DC cables are available for the users as part of the distribution chain connecting the power converters and the accelerator magnets. A robust, multi-users, optical fiber infrastructure is also available.

3.1.1. *High and low voltage networks*

Concerning the high-voltage (18 and 3.3 kV) network distributed from the SE buildings, the main users are the cryogenic system, the radiofrequency (RF) system, the water-cooling system, the general services, the power converters and the ventilation system. Figure 5 shows the distribution of the total loads of the different systems. About 70% of the loads are distributed and consumed at the ground level.

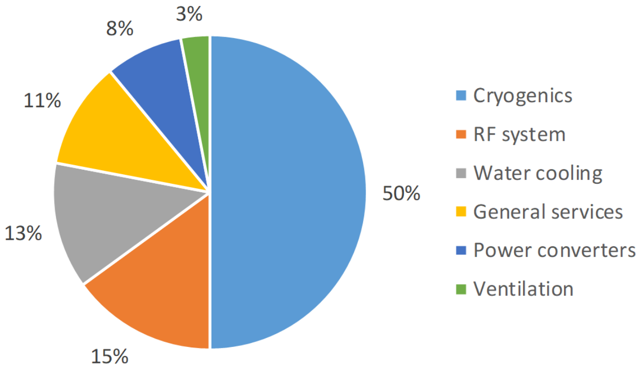

Fig. 5. Electrical load distribution.

The low-voltage (400 V) network is distributed in most of the surface and underground buildings for general services, machine network, secured network (backed-up by diesel generators) and uninterruptible power supply (UPS) network.

In the US caverns, a fireproof safe room is hosting all safety-related equipment. Secured network, supplied by diesel generators, is distributed to guarantee the supply of the critical ventilation and access system. The corresponding load is about 80 kW per point. Secured network, supplied by UPS, is constituted by several UPS units (double-conversion AC/DC) associated with batteries and 400-V distribution switchboards. The UPS system has a 10-minute autonomy and a nominal capacity of 250 kW per point. The main UPS users are the power converters, the RF system, and the interlock & energy extraction systems. The electrical safety systems include the emergency lighting and the emergency stop system (AUG) which acts on the 18-kV distribution network.

Finally, an optical fibre infrastructure provides optical fiber links across the CERN site, including in between surface and underground buildings. This infrastructure serves a variety of systems and is designed to cover the upcoming requests and to guarantee a minimum available fiber capacity in the service areas.

The electrical distribution is controlled via industrial PLCs and SCADA supervision systems and is integrated is the existing control architecture.

3.1.2. *High current DC cabling*

High Direct Current (DC) cables are used between the power converters and the cold powering system. Those power cables are either conventional (air-cooled ACC) for current ratings below 600 A, or demineralized-water-cooled (WCC) for current ratings above 600 A. To limit the forces and torques on the terminal, a minimum length of straight cable (from 150 mm for 120-A cable up to 500 mm for 18-kA cable) and a minimum bending radius (from 150 mm for 120-A cable up to 800 mm for 18-kA cable) must be respected. Per Point, the resistive dissipations in the power-converter galleries of these cables are 420 kW on the water-cooling circuit and 30 kW on the air ventilation system. Figure 6 shows a water-cooled DC cable. Table 1 gives the DC cable characteristics.

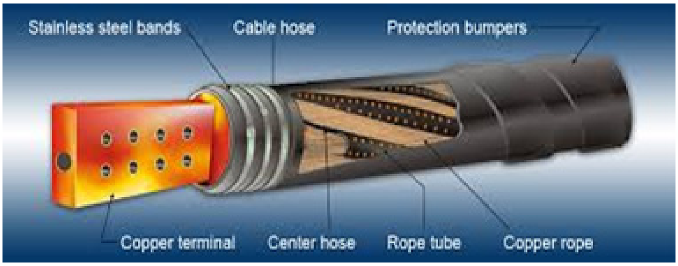

Fig. 6. Water-cooled DC cable.

Table 1. DC cable characteristics.

	Cable type	Circuit current [kA]	Section [mm^2]	From	To	# of cables [-]	Unit length [m]	Total length [m]
IT cluster	WCC	18	1300	PC	CDB	4	9	36
	WCC	14	2000	PC	CDB	2	20.5	41
	WCC	2	500	PC	CDB	16	23.3	372
	ACC	2	300	CDB	CL	56	4.4	246
	ACC	2	240	PC	EE	24	1	24
D2 cluster	WCC	14	2000	PC	CDB	2	8	16
	ACC	0.6	300	PC	CL or EE	20	3.8	76

PC: Power Converter; CDB: Circuit Disconnector Box; EE: Energy Extraction

4. Cooling and Ventilation

The cooling and ventilation plants at P1 and P5 are mostly the same. The only difference between the two installations consists in the heating solution for the air-handling units: at P1 (in Switzerland), a dedicated extension of the super-heated water network is used; at P5 (in France), electrical heaters are deployed.

4.1. *Water cooling*

4.1.1. *Primary water cooling*

A new 3-cell cooling tower of 5 MW per cell is installed in each point. The total cooling power requirement is about 8 MW and can be supplied by 2 cells, the third cell is used as a back-up. The water supply temperature varies between 20°C and 25°C. The primary water flowrate is based on 10-K temperature difference between supply and return. Three circuits distribute the primary water in a duty and standby arrangement. Table 2 gives the circuit cooling requirements and Figure 7 shows the cooling water architecture. The pump heads are selected to provide approximately 3 bar at the connection point of each user equipment. The new plant room houses the pumps, the sand filtration, water treatment station, and frost protection systems. The pipeline is made of stainless steel and distributed in the various buildings using technical galleries.

Table 2. Primary water circuit requirements.

Circuit	From SF to	Final users	Cooling need [MW]
1	SHM and SD	cryogenics	5.4
2	UW	Power converter, RF system & cryogenics	1.6
3	SU	Water-cooled chillers	0.8

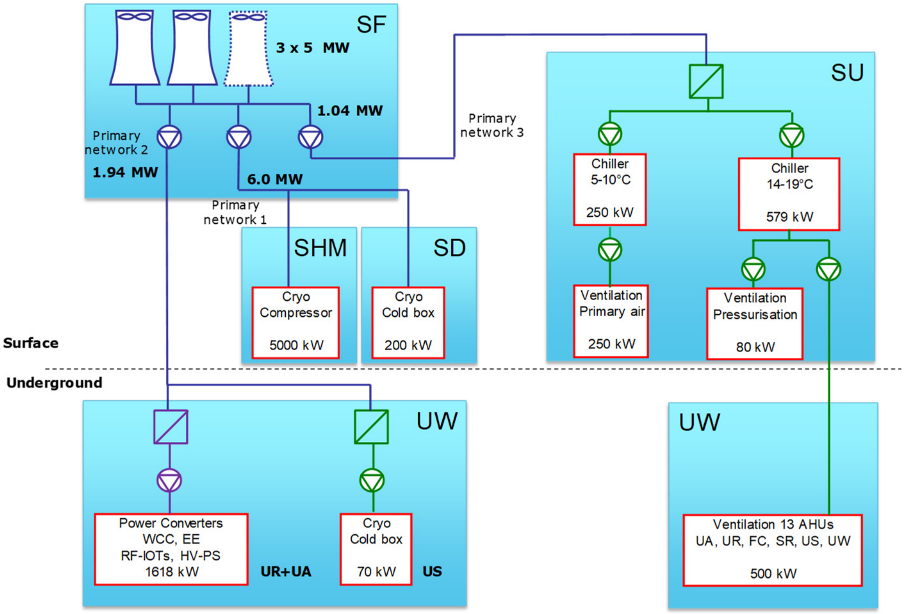

Fig. 7. Water cooling architecture.

4.1.2. *Secondary water cooling*

The cold compressors of the cryogenic system is cooled by a dedicated water cooling station in UW. It includes a heat exchanger of 70 kW and a duty and standby pump.

One demineralized water-cooling circuit is installed to service all the underground infrastructures. It cools the power converters, the water-cooled DC cables, and the RF system. The station includes one heat exchanger (1.6 MW), a duty and standby pump and a demineralizer, which guarantees a water conductivity below 0.5 μS/cm.

4.1.3. *Chillers and cold-water cooling*

Chilled water is needed for the fresh air handling unit. A duty and standby water-cooled chillers of 200 kW each are installed in the SU buildings and connected to a common 3-m^3 water buffer tank. The temperature regime is 6°C at the supply and 12°C at the return. The chilled water is distributed to the fresh air-handling unit.

Cold water for air handling units is also produced in the SU buildings. Two duty and a standby water-cooled chiller of 300 kW each are installed and connected to a common 5-m^3 water buffer tank. The temperature regime is 14°C at the supply and 20°C at the return. The cold water is distributed to the surface air-handling units. The water is distributed using duty and standby pumps and insulated stainless-steel pipework.

4.2. ***Ventilation***

4.2.1. *Underground ventilation*

The underground temperature is maintained between 14°C and 25°C using cold water (14-20°C). The heating, ventilation, and air-conditioning (HVAC) system consists of several ventilation units located as close as possible to the equipment generating the heat load. Table 3 gives the characteristics of the underground air-handling units. When existing, the air supply and return ducts have regular spaced grids. Figure 8 shows the underground ventilation architecture.

Table 3. Underground air-handling units (per Point).

Location	Number	Capacity [m^3/h]	Duct DN [mm]	Heat load [kW]	Comments
UR	6	8’500	n/a	90	
UA	2	15’000	900	2 x 56	
US	1	12’000	710	23	
UW	1	4’500	500	7	
Faraday cage	2	3’500	450	2 x 6	
Safe room	2	3’500	450	10	1 duty and 1 standby unit

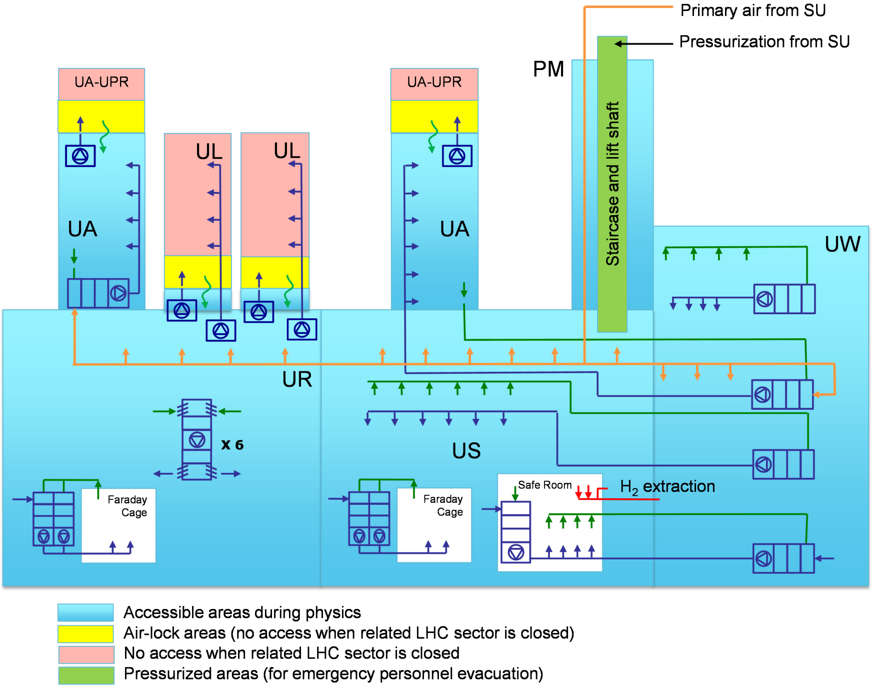

Fig. 8. Underground ventilation architecture.

The fresh air distribution in the underground structures is provided by one duty and one standby air-handling units of 15,000 m3/h each installed in SU17 and is ensuring the air renewal and the dehumidification of the tunnel. The air dew point is maintained below 12°C. Each unit uses chilled water for cooling (200 kW) and two hot water (P1) and electrical batteries (P5) (2 X 120 kW) for heating. The main supply air duct has a diameter of 800 mm thermally insulated.

A duty and standby unit of 15,000 m3/h is ensuring the pressurization of the staircase, lift shaft to the underground areas and safe area around the lift exit in the US. The supply air duct is constructed with circular ducts of 800 mm where possible. The air intake duct and supply ducts are insulated.

Two redundant ventilation systems ensure the pressurization of the airlock installed in the UA and UL service galleries. The units take fresh air from to pressurize the air-lock areas. These pressurizations prevent the migration of activated air present in the LHC tunnel.

4.2.2. *Smoke extraction*

Each surface building is equipped by a dedicated and independent smoke extraction system. The smoke extraction is ensured by natural ventilation using dedicated sky domes.

Two fans of 36,000 m3/h each are installed out of the SU to assure the smoke extraction form the underground buildings. A fire-resistant duct collects the smoke in the underground structures which are sectorized by doors and smoke curtains. Figure 9 shows the smoke-extraction architecture.

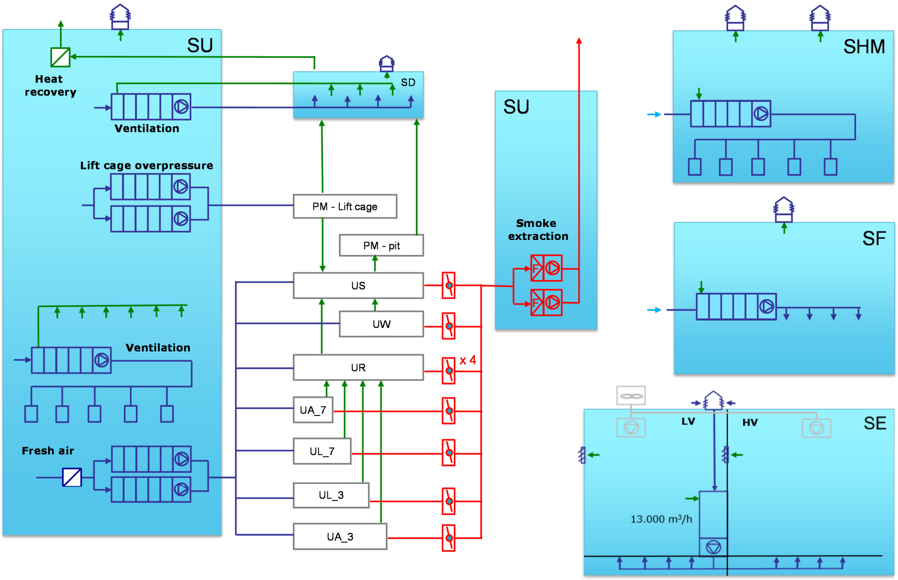

Fig. 9. Surface ventilation and smoke-extraction architecture.

4.2.3. *Surface building ventilation*

The required outside fresh air is provided by the ventilation systems in all the surface buildings. Depending on the building and on the required cooling capacity, the unit flowrates range from 2500 to 60’000 m^3/h. The air-intake ducts are thermally insulated. The HVAC units run in free cooling mode to save energy, except the SU unit, which is designed to run both with mixed water and in free cooling. The over-pressure is released using several static exhausts (or louvered penthouse). Figure 9 shows the surface ventilation architecture.

5. Alarm and Access System

The new underground areas must be constructed to fulfil the regulations for fire and radiation safety as well as oxygen deficiency hazards (ODH). All critical alarms are sent to the fire brigade for immediate interventions.

The LHC access safety system (LASS) ensures the personnel safety in the various operation modes of the LHC. 220 fire detectors, 74 ODH detectors, 16 radiation detectors and 50 red telephones (in direct line to the fire brigade) are equipping the new buildings and underground structures. Positions of doors allowing the access to the LHC tunnel are also monitored and interlocked with the LHC operation. An emergency evacuation system is based on audible evacuation signals triggered either automatically or manually by pushing one of the evacuation buttons. Figure 10 shows the underground access zoning and access elements.

An automatic protection safety system launches safety functions in case of fire or ODH detection. These functions are compartmentalization, evacuation, and smoke extraction. If necessary, the CERN fire brigade has the possibility

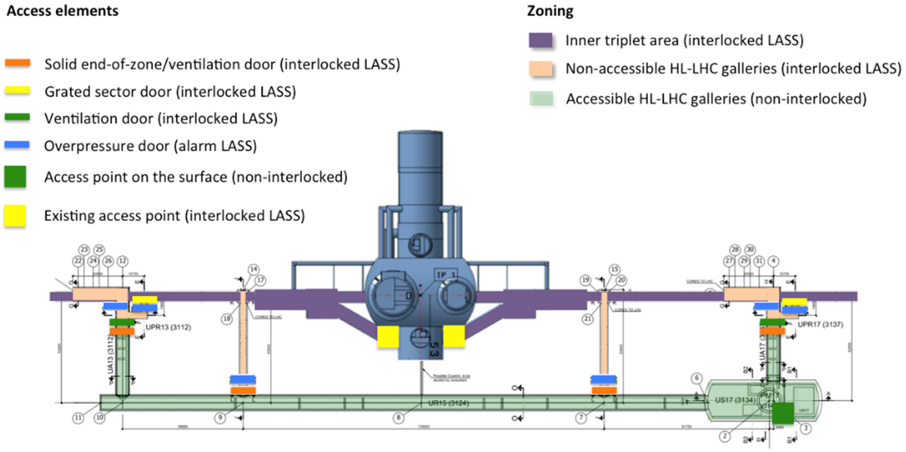

Fig. 10. Underground access zoning and access elements at Point 1 (zoning of Point 5 is similar except for existing access point and service tunnel locations).

of triggering these functions remotely and the possibility to sound safety instructions to the HL-LHC area.

For personnel access to underground structures, a control system located at the shaft lift entrance reads the personnel badges, checks the access rights, verifies the identity via biometric check, and authorizes the access if all conditions are fulfilled. Access to interlocked areas may be possible either in general mode or in restricted mode. Restricted mode is meant for accessing the machine in ready-for-beam conditions, and the user must be in possession of a safety token and the attached restricted mode key. The safety tokens ensure that the beam cannot be entered into the machine until the token is returned to its place in the token distributor. The new normally accessible underground areas of the HL-LHC are of non-interlocked type, which means that no safety tokens are necessary.

Access and safety equipment are generally powered by the CERN secure power grid. All critical functions are also secured by uninterruptible power supplies (UPS).

Concerning communication, the standard CERN GSM network (leaky feeders) is deployed in the HL-LHC structures. A TETRA secure communication system is using the same GSM network.

6. Technical Monitoring Network

All installed equipment is monitored for important operational data, events, and alarms. The low-level monitoring of each subsystem depends on the exact equipment and data collection framework used by that subsystem. Delivery of high-level surveillance and alarm information to CERN operators is realized via the CERN Technical Infrastructure Monitoring system (TIM), which acquires the required data items and alarms from the local SCADA-systems or directly from the monitored equipment.

A technical monitoring network is installed in both the surface buildings and the underground structures. This covers cabled connections to CERN General Purpose Network (GPN) and Technical Network (TN) as well as Wi-fi connections in selected areas. In underground areas, cabled connections are provided at regular distances in the galleries so that modern network-connected equipment can take advantage of it. Wi-fi coverage requires installation of a starpoint rack at approximately every 70-80 meters. All surface buildings have cabled connections at regular distances. Wi-fi coverage is limited to the more frequented areas (control rooms, rack areas, etc.).

7. Transport and Handling

Transport and handling equipment are installed in new surface buildings and underground structures.

A lift for personnel and materiel transport is installed in the shafts. The specifications are based on LHC 3-ton lifts which cover 90% of transport requirements. The safety requirement covers LHC specific risks (over pressurized shafts in case of fire or helium leak) and the lifts are fed by UPS and have a safe communication with the fire brigade so that they are used as evacuation exits in case of incident in the underground structures.

The electric overhead cranes for surface buildings & caverns are based on requirements from users, including size and weight of biggest/heaviest object to be transported to define parameters such as clearance under hook, span, and length. These designs integrate technical and legal requirements for the crane installation, operation, and maintenance, such as the clearance above the cranes and the catwalk to provide access to the rails and to the machinery. Table 4 gives the characteristics of the main electric overhead travelling cranes.

The UA galleries are permanently equipped with manual overhead cranes travelling on rails to allow for handling and transport of the radiofrequency components. In both Points, one UL gallery is permanently equipped with

Table 4. Main electric overhead travelling crane characteristics.

Location	Capacity [t]	Height hook [m]	Lifting height [m]	Hopper		Speed	
				Length [m]	Span [m]	Max [m/min]	Min [m/min]
SHM17 / 57	20	6	6	50	15	5	0.25
SD17 / 57	25	10	100	28.4	16.1	20	0.5
SF17 / 57	3.2	9	9	23	10	5	0.25
SU17 / 57	7.5	8	8	16	14	5	0.25
US17 / 57	5	7.5	7.5	26	12	5	0.25
UW17 / 57 (top)	3.2	3.2	3.2	15	6	5	0.25
UW17 / 57 (floor)	3.2	3.2	3.2	15	6	5	0.25

manual cranes travelling on rails to allow for handling and transport during maintenance of cryogenic components. These manual overhead cranes have a capacity of 1 ton.

Hoists complete the handling equipment inventory. Water sumps are equipped with heavy lifting pumps that need to be maintained. The support for the hoist is permanently installed on site. Only one hoist unit is requested and is used on demand and moved from one point to another. The equipment, tools and materials necessary for the maintenance of the equipment located in the UW cavern upper floor are transported from the US side. A small hopper with a dedicated 500 kg hoist is permanently installed to lift the tools and consumables. In the SHM buildings, a hoist on a rail is required to transfer the load in the second bay of the building.

For installation of the large cooling & ventilation equipment and all heavy equipment's located in the UW upper floor, a 5-t drawbridge is permanently installed inside the shaft of the US caverns in Points 1 and 5.

8. Operational Safety

Doors and their corresponding frames are required to guarantee the sectorization, the safety and the evacuation of personnel in the caverns and underground galleries. The corresponding instrumentation and controls of these doors are handled by the LHC access safety system (see Section 5). Smoke curtains are also required to implement fire compartments for smoke extraction. In addition, at the surface, sectional doors are installed on the main buildings. The SHM sectional doors are equipped with an anti-noise curtain. Table 5 gives the characteristics of the doors and curtains.

For the radioprotection of personnel, all UA galleries are equipped with 12-t mobile-shielding doors with electrical motors. The dimensions are: 2 m x 0.8 m x 2.8 m. These doors are moving on dedicated ground rails. In addition, 102 t of steel and 48 t of concrete blocks are used in the construction of shielding walls in the UL galleries.

Four firefighting vehicles are located in the UA galleries. These vehicles are composed of a tractor and a trailer. In addition, CO_2 fire extinguishers are periodically distributed in underground structures and surface buildings.

Table 5. Doors and curtain characteristics.

Type	Location	Total number	Size LxH [m x m]	Resistant category		Comment
				Fire	Pressure	
Ventilation and fire-resistant door	UA airlock system	4	1.3 x 2.4	EI 120	n/a	
Ventilation and end-of-zone door	UA airlock system	4	1.3 x 2.4	n/a	n/a	
End-of-sector door	UPR LHC side	4	1 x 2.1	n/a	n/a	Grating
Fire- & pressure-resistant door	UPR LHC side	4	1 x 2.1	EI 120	60 mbar	
Fire- & pressure-resistant door	UA	4	1.5 x 2.4	EI 120	60 mbar	
Fire-resistant door	UR	2	2.8 x 2.8	EI 90	n/a	
Fire-resistant door	UW	4	3 x 3	EI 90	n/a	1/3 - 2/3
Fire-resistant door	Safe room	2	2 x 2.45	EI 120	n/a	
Ventilation and end-of-zone door	UL airlock system	4	1.1 x 2.15	n/a	n/a	
Fire- & pressure-resistant door	UL airlock system	4	1.1 x 2.15	EI 120	60 mbar	
Ventilation and fire-resistant door	US lift airlock	2	2 x 2.65	EI 120	n/a	
Sectional door	SD	2	6 x 6	n/a	n/a	wall mounted
Sectional door	SF	2	4 x 4	n/a	n/a	wall mounted
Sectional door	SHM	2	5 x 5	n/a	n/a	wall mounted
Sectional door	SHM (CV room)	2	4 x 5	n/a	n/a	wall mounted
Sectional door	SU	2	5 x 5	n/a	n/a	wall mounted
Smoke curtain	UR	6	n/a	EI 90	n/a	
Smoke curtain	UA entrance	4	n/a	EI 90	n/a	
Smoke curtain	UL entrance	4	n/a	EI 90	n/a	
Noise curtain	SHM	2	5 x 5	n/a	n/a	