Chapter 17

Technical infrastructure

L. Tavian[1*], *M. Battistin*[1], *S. Bertolasi*[1], *C. Bertone*[1], *B. Di Girolamo*[1], *N. Dos Santos*[1], *K. Foraz*[1], *T. Hakulinen*[1], *P. Mattelaer*[1], *P. Muffat*[1] *and P. Pepinster*[1]

[1]CERN, Accelerator & Technology Sector, Switzerland
[*]Corresponding author

17 The HL-LHC technical infrastructure

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

17.1 Civil engineering

17.1.1 Introduction

In terms of civil engineering, the needs of the HL-LHC machine are, to a large extent, similar to the LHC machine, which was a considerable extension carried out between 1998 and 2005 of the previous LEP tunnel built in in the 1980's. These needs consist principally of access shafts from the surface to the underground areas together with various underground caverns and tunnels that, to distinguish from the LHC beam tunnel, we will call galleries. Buildings are required on the surface for housing compressors, ventilation equipment, electrical equipment and helium and nitrogen tanks.

The HL-LHC construction work will be split between two existing experimental sites, LHC Point 1 for the ATLAS experiment, located in Switzerland, and LHC Point 5 for the CMS experiment, located in France, and will include underground and surface works at both points.

The underground work at each point will consist of a shaft, a cavern, a power converter gallery, service galleries, safety galleries and vertical cores that link the new galleries to the existing LHC infrastructure. The civil engineering work encompass both the primary concrete and steel structures of the surface and underground structures as well as the secondary steel structures within the buildings and caverns. At both locations, some of the new work will be located close to existing LHC infrastructure. Hence, special protective measures must be taken in order to minimise impact on the operation of the LHC and on the LHC infrastructure itself.

To fulfil the HL-LHC timeline the majority of the construction will be completed in a 5-year period. Activities started in 2018 with the excavations of the shafts starting from the surface. The remaining underground excavation work close to the LHC tunnel area was scheduled during LS2, when the LHC operation is stopped, and the less invasive concreting and finishing of the underground work is scheduled during 2020–2021. The surface work is scheduled to take place from late 2019 to the end of 2022. Staged handovers of the new buildings are planned. The only construction work that is scheduled outside of this 5-year period are the drilling of the linkage cores from the new HL-LHC infrastructure into the existing LHC tunnel, which is scheduled for early 2025 when the LHC is again not operational during LS3. The objective is to also construct the safety galleries that connect the HL-LHC underground structures to the existing LHC tunnel during LS2 and have them operational during infrastructure installation that will take place during the LHC Run 3.

17.1.2 Underground work

For the HL-LHC additional underground space is required for services. The dimensions of underground structures specified for Point 1 and Point 5 are detailed in Table 17-1. However, for the HL-LHC there is no requirement for additional underground spaces as experimental caverns. As shown in Figure 17-1 the underground work consists of the structures described hereafter.

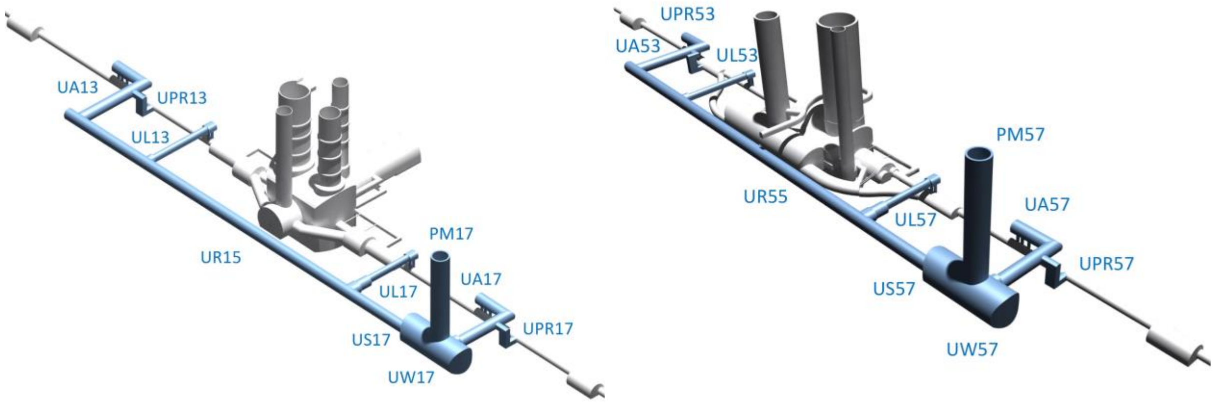

Figure 17-1: Point 1 (left) and Point 5 (right) indicative underground axonometric

Table 17-1: Underground structure dimensions at Point 1 (Point 5 if different)

Building Code	Building Name	Length (m)	Inside Width (at floor level) (m)	Height (m)	Radius (m)	Floor Area (m^2)	Volume (m^3)
PM	Shaft	-	-	72.0 (82.2)	5.00	79	5690 (9490)
US/UW	Cavern	46.3	14.7	11.2	8.00	681	6 924
UR	Power converter gallery	302.0	5.0	4.7	2.90	1522	7 013
UL	SC cryo link galleries	53.7	3.7	3.3	1.55	198	618
UA	RF galleries	68.1	5.7	4.4	2.90	389	1 579
UPR	Safety galleries	51.1 (54.3)	2.5	2.50	-	128 (136)	286 (304)

The shaft (PM) connects the surface with the underground area. A lift in the shaft provides day-to-day personnel and equipment access; it is housed in leak tight concrete modules which are over-pressurized with respect to the ambient pressure. Aa staircase is also included in these concrete modules. At the bottom and top of the shaft, there are pressurized safe rooms. All cryogenic, power and ventilation connections between the surface and the cavern pass through the shaft.

The underground caverns are made up of two portions: the US and the UW. They house the cryogenic equipment and other technical services. A concrete wall separates the US and UW portions. In the UW and large part of the US, there is a first floor supported by a steel structure to provide a two-storey facility.

The UR gallery, approximately 300-m long and placed parallel to the LHC tunnel, mainly houses the power converters and the electrical current feed boxes of the superconducting magnets. It is connected to the LHC tunnel via the service galleries.

Four service galleries (UA and UL) provide the connection from the UR gallery to the existing LHC tunnel for Point 1 and Point 5 each, via the vertical linkage cores. The UA galleries will house the RF equipment of the crab-cavities and the UL galleries will house the cryogenic distribution system and the superconducting links.

Vertical cores, of approximately 1 m diameter each, are required to pass services from each of the four service galleries to the existing LHC tunnel. These linkages allow connecting the newly installed services to the new systems (superconducting magnets, cryogenic distribution lines and RF cavities) that occupy the Long Straight Sections (LSS) in the existing LHC tunnel.

Finally, a safety gallery (UPR) for personnel is required to connect each UA gallery directly to the existing LHC infrastructure.

17.1.3 Surface work

All LHC buildings keep their present functionality during the HL-LHC era. In addition, some new buildings are required at Point 1 and Point 5. The surface work at each point is made up of 5 new buildings, a combination of steel and concrete structures, as well as technical galleries, concrete slabs, roads, drainage, and landscaping. At present, it is anticipated that the buildings would generate an additional 6200 m^2 of floor area. The dimensions for the surface structures at Point 1 and Point 5 are specified in Table 17-2. The corresponding site layouts are shown in Figure 17-2 and Figure 17-3. The surface works consist of the structures described hereafter.

The head-shaft building (SD) covers the PM shaft; a steel frame building is envisaged. The floor slab of the building requires technical galleries to allow cables, pipes, and other services to pass from the PM shaft to the service gallery and other adjacent buildings.

The ventilation building (SU) is required to house the equipment needed for the heating, ventilation, and air conditioning of the underground infrastructure. The building is constructed in reinforced concrete to minimise noise levels outside the building. The building is split into two sections that house compressors and air handling units, respectively.

The electrical building (SE) is used to house electrical equipment. The building includes a low voltage room, a high voltage room and a small room for UPS battery storage.

The cooling tower building (SF) is required to extract the heat loads from the equipment and is constructed in reinforced concrete. The building is split into two zones, one for the two cooling towers, and one for the pump room. This building is partially equipped with a steel mezzanine structure. Chemical products for water treatment are stored in a dedicated external container, which requires a dedicated concrete slab.

The compressor building (SHM) houses the warm compressors of the cryogenic plant. It is constructed in reinforced concrete. This building is partially equipped with steel mezzanine structures.

The technical galleries (SL) run just below ground level between the buildings in order to provide a route for power supplies, cryogenics, and cooling pipes. The siting of the new technical galleries is optimised such that there is no interference with existing services. There are some openings required in the roof of the galleries to provide access for the installation of services, extraction points and escape points. Some technical galleries are connected to existing buildings and galleries. The galleries must be watertight and are foreseen in reinforced concrete.

The helium tank platform (SHE) is a concrete foundation for placing 2 helium tanks on. The support for the tanks is based on a steel frame that is connected to the foundation using anchor bolts that can transfer seismic loads to the slab. A crash barrier is required around the structure.

The nitrogen tank platform (SLN) is a concrete slab for placing large nitrogen tanks on. The support for the tanks is based on a steel frame that is connected to the slab using anchor bolts that can transfer seismic loads to the slab. A crash barrier is required around the structure.

The harmonic filter slab will house the electrical equipment needed for the power quality of the electrical network. In addition, a slab for a new electrical sub-station housing a transformer is required at Point 5. The slabs at Point 5 are not included in the WP17.1 scope and are part of the WP17.2.

New roads and car parks are required to provide transport links to the new buildings. At Point 1, the existing terrain level is modified to create a platform at approximately the elevation of the ATLAS site. Spoils excavated from the underground structures are used to construct this platform.

Finally, required drainage for all the new surface and underground structures is fully integrated into the existing drainage system

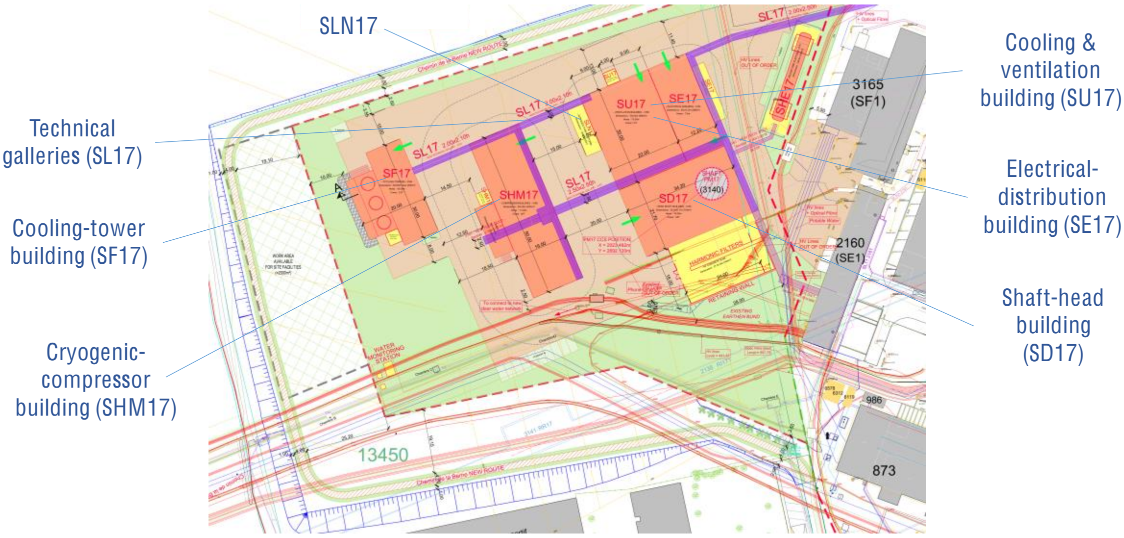

Figure 17-2: Point 1 surface layout

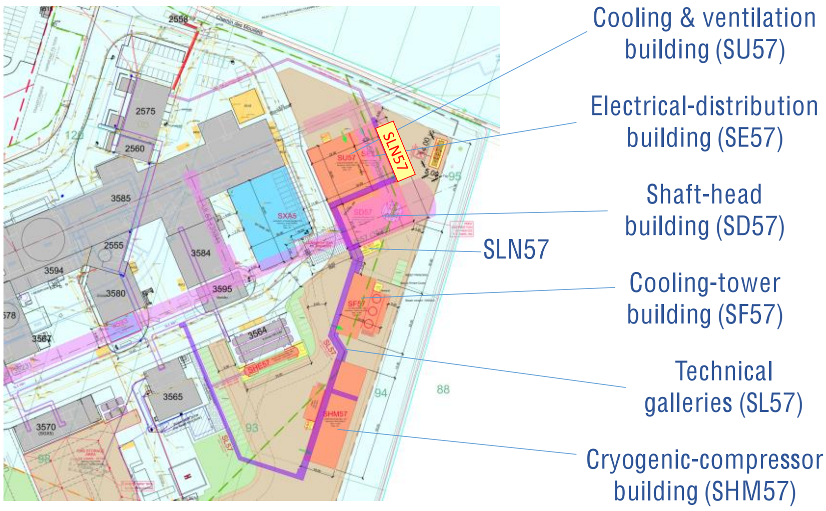

Figure 17-3: Point 5 surface layout

Table 17-2: Point 1 surface building characteristics (Point 5 if different)

Building Code	Building Name	Length (m)	Width (m)	Height (m)	Floor Area (m^2)	Volume (m^3)
SD	Head shaft building	32.0	20.0	16.0	640	10 200
SU	Ventilation building	30.0	22.0	13.5	660	8 910
SE	Electrical building	29.5	10.5	7.0	310 (352)	2 170 (2460)
SF	Cooling towers	19.0	18.1	7.7	344	2 648
SHM	Compressor building	56.0	16.0	10.9	896	9 770

17.1.4 Vibration risk to the LHC during construction

The impact of the HL-LHC construction on the LHC operation is a key constraint of the civil engineering of the HL-LHC project. It has been concluded that excavation of the caverns and various service galleries close to the LHC tunnel cannot take place whilst the machine is in operation. Hence, these activities have been scheduled during LS2. The decision was taken at the end of 2015 and required advancing the whole HL-LHC civil engineer by two years with respect to the original plan. The shaft has been located as far as possible from the triplets and is located 40 m from the existing infrastructure; its construction has been deemed possible whilst the LHC was running, during the last year of Run 2 (2018). The experience proved that this decision was right since no problem of vibrations has been actually affected the LHC operation. The concreting/finishing phase of the underground construction will be completed in 2021: again, we do not expect any issue for the LHC operation due to vibrations from this construction phase.

17.2 Electricity

17.2.1 Objective

This Section outlines the new infrastructures needed for the HL-LHC in terms of electrical distribution, optical fibre infrastructure, Direct Current (DC) distribution and signal cabling. The design principles presented in the document are based on the requirements formulated by the users in 2016. A recent revision of the user-load requirement might imply some modifications of the electrical distribution system. A more detailed description can be found in [1].

17.2.2 Requirements and constraints

From an environmental point of view, the new electrical infrastructure required for the HL-LHC may imply risks in term of noise. The noise level generated by electrical equipment, such as transformers or switchgear, have been provided to an acoustic consultant, which has performed studies both for surface and underground installations. In addition, all the distribution transformers (excepted for the 66/18 kV transformer at Point 5) installed in the context of the HL-LHC will be of dry type and therefore do not create problems in relation to oil pollution.

The schedule for the work outlined in the next Sections is strictly related to the hand-over of the surface buildings and underground structures foreseen by the project.

Part of the work related to the transport and distribution infrastructure, such as the installation of the infrastructures in the new underground caverns and surface buildings, can be carried out during the run of the accelerators. A large part, especially related to the modifications to existing infrastructure, needs to be executed during an Extended Year End Technical Stop (E)YETS or during a Long Shutdown (LS) when the accelerators are not being operated.

In Point 1, the constraints related to the construction of the new buildings require the displacement of existing power cables and optical fibres, which was executed during the EYETS 2016 in order to limit the risk of loss of availability of user systems.

In order to minimize the impact of cumulated dose received during the future maintenance interventions and to adequately select the components to be installed in the radiation areas, the radiation data collection has started and is under analyse in collaboration with HSE-RP. The installation work in the LHC tunnel is organized in campaigns according to the correspondent activities and following the ALARA (*As Low As Reasonably Achievable*) principle to minimize the cumulated dose received by the participants.

It is necessary to underline that the technical solutions specified by the users have an important impact on both power requirements and integration in underground facilities. For example, in the case of radio frequency (RF) systems, the worst-case scenario in terms of power consumption and integration is represented by the use of power amplifiers with IOT technology, while the best-case scenario is represented by the use of

Solid State Power Amplifiers (SSPA). While the HL-LHC baseline after the C&SR4 includes SSPAs for the crab cavities, the design described in this document is still based on the use of IOTs which is the more demanding reference from the integration point of view and foresees to supply 4 crab-cavity modules per Point.

The following Sections cover the design principles related to the distribution network, which covers 18 kV, 3.3 kV and 400 V as well as optical-fibres and DC cables. The design principles used for the distribution network are the same at Point 1 and 5, allowing an important level of standardization, and are based on the present LEP and LHC principles for what concerns power transmission.

17.2.3 User electrical load forecast at Point 1 and Point 5

The load forecast of the HL-LHC project has been evaluated by the main users (cryogenics, radiofrequency, power converters, cooling and ventilation) and is summarized in Table 17-3. The differences between the two Points are due to additional building electrical heating at Point 5.

At Point 1, the HL-LHC loads are fed via the existing transformer EHT102/1E, which has sufficient design margins to supply these extra HL-LHC loads as well as extra loads due to the ATLAS detector upgrade. The Point 5 of LHC is presently supplied via an existing 18 kV 15 MVA line coming from LHC Point 6. This existing line is definitely not adapted to the new loads foreseen at Point 5, both for the HL-LHC and the CMS detector upgrade. Consequently, a new 66 kV line coming from LHC Point 6 is foreseen in the CERN consolidation plan (i.e. outside of the HL-LHC project scope). On the Point 5 site, a new electrical substation equipped with a 66/18 kV electrical transformer of 38 MVA must be added and is part of the WP17.2 scope.

Table 17-3: HL-LHC loads in Point 1 and Point 5

		Point 1				Point 5			
User	**Location**	**(kW)**	**(kvar)**	**(kVA)**	**cos(phi)**	**(kW)**	**(kvar)**	**(kVA)**	**cos(phi)**
Cryogenic system	SHM	5000 (5320)	2967 (3157)	5814 (6186)	0.86	5000 (5320)	2967 (3157)	5814 (6186)	0.86
Ventilation	SE	8 (36)	4 (27)	9 (45)	0.9 (0.8)	8 (36)	4 (27)	9 (45)	0.9 (0.8)
Ventilation	SU	32 (44)	16 (33)	36 (55)	0.9 (0.8)	32 (44)	16 (33)	36 (55)	0.9 (0.8)
Ventilation	SF	49 (51)	24 (38)	55 (64)	0.9 (0.8)	43 (221)	21 (166)	48 (276)	0.9 (0.8)
Ventilation	UW	62 (20)	30 (15)	69 (25)	0.9 (0.8)	62 (20)	30 (15)	69 (25)	0.9 (0.8)
Ventilation	SHM	31 (32)	15 (24)	35 (40)	0.9 (0.8)	31 (32)	15 (24)	35 (40)	0.9 (0.8)
Ventilation	UR	0 (32)	0 (24)	0 (40)	0.9 (0.8)	0 (32)	0 (24)	0 (40)	0.9 (0.8)
Ventilation	UA	0 (6)	0 (5)	0 (8)	0.9 (0.8)	0 (6)	0 (5)	0 (8)	0.9 (0.8)
Ventilation	US	0 (6)	0 (5)	0 (8)	0.9 (0.8)	0 (6)	0 (5)	0 (8)	0.9 (0.8)
Cooling	SU	606 (566)	293 (425)	673 (708)	0.9 (0.8)	606 (566)	293 (425)	673 (708)	0.9 (0.8)
Cooling	SF	549 (520)	266 (390)	610 (650)	0.9 (0.8)	549 (520)	266 (390)	610 (650)	0.9 (0.8)
Cooling	UW	164 (138)	79 (104)	182 (173)	0.9 (0.8)	164 (138)	79 (104)	182 (173)	0.9 (0.8)
Radiofrequency	UR/UA	807 (444)	265 (146)	849 (468)	0.95	807 (444)	265 (146)	849 (468)	0.95
Radiofrequency	US/UA	807 (444)	265 (146)	849 (468)	0.95	807 (444)	265 (146)	849 (468)	0.95
Power converters	UR	1300 (1014)	700 (814)	1368 (1300)	0.95 (0.75)	1300 (1014)	700 (814)	1368 (1300)	0.95 (0.75)
Cold powering	UR	0 (20)	0	0 (20)	1	0 (20)	0	0 (20)	1
Machine protection	UR	0 (24)	0 (12)	0 (27)	0.9	0 (24)	0 (12)	0 (27)	0.9
Survey		0 (65)	0 (31)	0 (72)	0.9	0 (65)	0 (31)	0 (72)	0.9
EL network Control		0 (2)	0	0 (2)	1	0 (2)	0	0 (2)	1
Transport		0 (316)	0 (204)	0 (376)	0.78	0 (316)	0 (204)	0 (376)	0.78
Various	Surface Underg.	1000	800	1281	0.78	1000	800	1281	0.78
(xxx): Revised estimate		10416 (10100)	5725 (6398)	11830 (11956)		10913 (10300)	5965 (6548)	12383 (12205)	

17.2.4 Power quality at Point 1 and Point 5

The operation of the HL-LHC accelerator imposes the need for excellent power quality. In particular the power converters, controlling DC currents with highest precision of a few ppm are very sensitive to power quality issues. Consequently, to compensate for the reactive power consumption of the HL-LHC load, and to filter the higher frequency harmonics, two new high-pass filters are required at Point 1 and Point 5. Each of these harmonic filters will be switched individually by a dedicated 18 kV circuit breaker, allowing to adapt the reactive power generation. The ratings of the components for these two harmonic filters will be based on CERN's standardised harmonic filter design. The achieved power quality level will be in conformity with the requirements of the CERN LHC Engineering Specification EDMS113154 and with the international standard IEC 61000-2-4 Class 1. Table 17-4 gives the main characteristics of these filters.

Table 17-4: Main characteristics of harmonic filters

Location	Reactive power rating of filter #1 (Mvar)	Reactive power rating of filter #2 (Mvar)	Connected to substation
Point 1	6	6	EMD8/1E
Point 5	6	4	EMD2/5E

17.2.5 User electrical load forecast at Point 4

Following a Decision Management Report to not install at Point 4 the mobile helium refrigerator presently used for the SPS test station of crab-cavity cryo-modules, no additional electrical load is required at Point 4.

17.2.6 High voltage distribution network

The detailed single line diagrams are given in [2] and [3] for Point 1 and Point 5 respectively. As previously mentioned, the 18 kV and 3.3 kV distribution in Point 1 and Point 5 are designed to be as similar as possible. The main users are the cryogenic systems (SHM), the cooling and ventilation (SU, SF, UW), the radio frequency system (UA) and the power converters (UR).

The electrical-distribution building (SE) contains 3 rooms. The first room, called SEH, hosts 18 kV and 3.3-kV switchgear. The second room, called SES, hosts 18 kV and 3.3 kV protection relays, 400 V main and secondary distribution switchboards (normal and secured network), safety lighting power sources and distribution switchboards, 48 VDC system (chargers and distribution), UPS units, equipment control/supervision racks and emergency stop rack. The third, smaller room, hosts batteries for the 48 VDC system and the UPS.

In the US cavern, a fireproof safe room is created to host all safety-related equipment. The safe room contains main and secondary secured switchboards, 48 VDC systems (chargers, distribution, and batteries) and emergency stop racks.

The equipment to be installed in SE buildings, safe rooms and underground facilities has been defined and integrated in the 3D model on the basis of EL known needs, user requirements and affinity with existing LHC installations.

17.2.7 Low voltage distribution network

The low voltage distribution topology is based on the one currently used for the LHC and based on the available amount of information provided at this stage by the users. Four main functional networks are foreseen to be distributed in most of the surface and underground buildings: general services, machine network, secured network (backed-up by diesel generators) and uninterruptible power supplies network (UPS).

In Point 1, the General Services Network is fed by one 18/0.4 kV transformer, located outside SE17, and supplied by the 18 kV switchgear EMD1/1E installed in SE1. The main 400 V distribution switchboard

EBD1/17E feeds all general services sub-switchboards installed inside surface buildings and underground facilities. The Machine network is fed by several 18/0.4 kV transformers distributed along the machine buildings; on the secondary side of each transformer, one main 400 V switchboard will distribute the power to various users. The low voltage distribution network is described in Ref. [4] for Point 1 (Point 5 follows the same principles).

17.2.8 Secured power systems

This Section describes the design principles of the low voltage distribution related to the diesel generators, the UPS systems and 48 VDC systems.

In Point 1 and Point 5, the load forecast is estimated to 167 kW dedicated to ventilation safety systems and lifts and does not indicate the need of a major modification of the existing infrastructure. In Point 1, the secured network dedicated to the HL-LHC loads is fed by one 18/0.4 kV transformer, located outside SE17, and supplied by the 18 kV switchgear EFD1/1E installed in SE1. The main 400 V distribution switchboard ESD1/17E feeds all secured sub-switchboards installed inside surface buildings and underground facilities. In Point 5, the estimated loads imply the replacement of the existing diesel generator which is limited to 78 kW or the installation of a new one (space has been reserved for this scope). The distribution principle will be similar to the one described above for Point 1.

The UPS network is constituted by several UPS units (double-conversion AC/DC) associated with batteries and 400-V distribution switchboards. The UPS have a 10-minute autonomy; underground UPS will be installed with N+1 redundancy. The UPS and related switchboards are installed and rated according the user needs. Depending on this, the UPS can be installed with a centralised configuration, in which a single UPS supplies different functional equipment, or with a single unit dedicated to a specific user. The load forecast, presented in Table 17-5, highlights the needs of UPS in both Point 1 and Point 5.

Table 17-5: Load forecast for the UPS in LHC1 and LHC5

	Location	P1 P (kW)	P5 P (kW)	Comment
Power converters	UR	86	86	1kW/ converter
	SR	10	10	IOT option
Radio Frequency	UR	70	70	Tetrode option
Cryogenic Systems	SHM	5	5	Extrapolated from LHC
	SDH	5	5	Extrapolated from LHC
	US	10	10	Extrapolated from LHC
Interlock and Energy extraction	UR	65	65	Redundant powering with 2 UPS lines, 10 min autonomy
Cooling & Ventilation		0	0	
Total		251	251	

In addition to the networks described above, a 48 VDC network supplies the auxiliaries of high voltage switchgears and low voltage switchboards, the emergency stop systems and Scada-related equipment. The 48 VDC network is constituted by Ni-Cd batteries, distribution switchboards and battery chargers fed by 400 V secured network. Only WP17.2 equipment is connected to the 48 VDC network.

17.2.9 Safety systems

Dedicated emergency lighting systems are installed in every surface and underground facility. The emergency lighting system is activated in the event of a power failure or a scheduled test. For the underground facilities, it is foreseen to install a centralized and redundant system, with two different and independent sources, separate fireproof cabling, and specific luminaires. Surface buildings, more likely, are equipped with safety luminaires for an emergency evacuation. These luminaires have their own batteries and act in the event of a power failure or a scheduled test. The lighting levels and distribution are according to the last safety norms applicable at CERN.

The emergency stop system, so-called AUG, is constituted by two racks: one in the surface building SE and one in the safe room inside the US cavern. Surface buildings and underground facilities are subject to the action of Emergency Stop Buttons, which act on the 18 kV distribution network. In the event that an AUG is activated, the CERN fire brigade is called immediately (Level 3 alarm) and all electrical powers are lost until their restoration by the stand-by duty service. A risk assessment shall be conducted in accordance with IS5 to decide the scope of services affected by an AUG action.

17.2.10 SCADA System

The electrical equipment of the CERN power distribution network is interfaced with the existing SCADA system, referred to as ENS, Electrical Network Supervision, which provides the CERN Control Centre (CCC) and the electrical operation personnel with remote monitoring, control facilities, alarm information and historical archiving. The SCADA system supervision covers from simple status signals to digital protection relays as well as UPS and battery chargers. Control channels permit remote actions mainly on circuit-breakers, UPS, and battery chargers. Majority of devices involved at various levels are synchronised from Time Servers through NTP protocol. In addition to the conversion of multiple communication protocols from field equipment towards the upstream IEC870-5-104, RTUs allow for a second level of supervision in the major substations through local SCADA software. The implementation is “stand-alone”, remaining fully operational in the event of unavailability of the external informatics infrastructure or main SCADA system. In the context of the HL-LHC, two new RTU will be installed per LHC point (1 and 5), one in the SE building and one in the US cavern, centralizing the supervision of electrical equipment respectively in all new surface and underground buildings.

The main SCADA system, Siemens WinCC OA based (formerly known as PVSS) runs on 2 LINUX servers in a redundant hot-standby configuration. The system is integrated with existing CERN facilities for long term archiving and logging, for alarms and for data exchange with other applications and control systems.

17.2.11 High current DC cabling

In the HL-LHC Project, high Direct Current (DC) cables are used between the power converters and the superconducting-circuit current leads, which are integrated in the DFH or cryo-magnet assemblies. Those chlorine-free power cables are either conventional (air-cooled) or water-cooled depending on the current requirements. The design of the terminations is adapted to the power converters and to the current leads of the DFBs. Table 17-6 and Figure 17-4 show the intensity of the current requested and the cross-section of the cables. Conventional Air Cooled Cable (ACC) are used for the following intensities: 35, 120, 200 and 600 A. The cross-section of the conventional DC cables is defined in the Reference Database, which contains all information related to the Electrical DC Circuits. Their installation is included in the machine cabling campaigns. Water-Cooled Cables (WCC) are used for high current DC interconnections between the power converters and the circuit disconnector boxes, located in the UR galleries of the points 1 and 5 of LHC. The WCCs concern the following intensities: 2, 13 and 18 kA. The cooling of the cables is assured by the circulation of demineralized water inside the cable hose. This technology is well known at CERN and currently used in all the points of the LHC. For the other circuits Q4, Q5, Q6 and their correctors, the existing DC cables already installed in the RRs are reused.

The bending radius of the cables is given in Table 17-6. Due to the configuration of the civil engineering of the UR building, the 18 kA link is composed of 2 cables of 1300 mm^2 in parallel for each one of the polarities to limit the height necessary for the bending radius of the cables. The space required for the links has been reserved in the integration database. The supports of the cables located above the power converters and the current leads have to be carefully designed in order to avoid stress on the equipment and connectors and to allow easy operation. According to the actual layout, the main characteristics and the total length of the DC cables are shown in Table 17-7. The lengths are identical for both sides of each Point. In the UR, the cable resistive losses are 420 kW per Point dissipated in the demineralized water and 30 kW per Point dissipated the UR ventilation system.

	Copper section [mm²]	Length of the cable above the lug h: [mm]	Minimum bending radius r: [mm]	External diameter [mm]
18 kA	2x1300	500	800	2x95
13 kA	2000	500	800	115
6 kA	1000	500	700	95
2 kA	500	500	500	70
600 A	400	300	300	36
200 A	95	200	200	25
120 A	70	150	150	22

Table 17-6: Intensity requested and cross-section of the cables

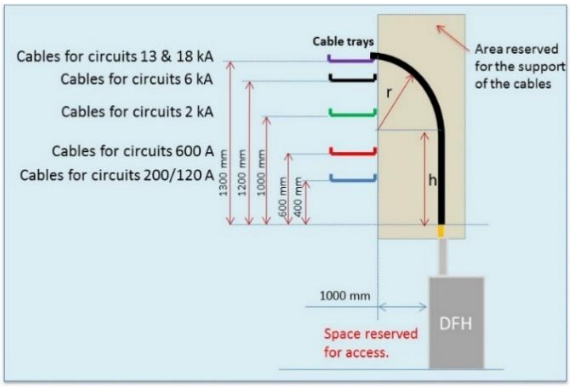

Figure 17-4: Bending radius of the DC cables

Table 17-7: DC cable characteristics

Optic	Magnet	PC location	CL location	Current (kA)	# of circuits per side	Cu section (mm²)	Unit cable length (m)	# cable per polarity	# of sides	Total cable length (m)	Type
Q1-Q2a-Q2b-Q3	MQXFA / MQXFB	UR	UR (DFHX)	18	1	1300	42	2	4	672	WCC
Trim Q1		UR	UR (DFHX)	2	1	500	60	1	4	480	WCC
Trim Q3		UR	UR (DFHX)	2	1	500	28	1	4	224	WCC
Corrector	MCBXFBV	UR	UR (DFHX)	2	2	500	64	1	4	1024	WCC
Corrector	MCBXFBH	UR	UR (DFHX)	2	2	500	66	1	4	1056	WCC
Corrector	MCBXFAV	UR	UR (DFHX)	2	1	500	70	1	4	560	WCC
Corrector	MCBXFAH	UR	UR (DFHX)	2	1	500	72	1	4	576	WCC
D1	MBXF	UR	UR (DFHX)	13	1	2000	44	1	4	352	WCC
D2	MBRD	UR	UR (DFHM)	13	1	2000	36	1	4	288	WCC
Correct D2	MCBRD	UR	UR (DFHM)	0.6	4	400	24	1	4	768	ACC
Kmod Q1a		LHC UJ	IT cryostat	0.035	1	20	120	1	4	960	ACC
CP	MQSXF	LHC UL & UJ	IT cryostat	0.2	1	120	75	1	4	600	ACC
CP	MCSXF / MCSSXF	LHC UL & UJ	IT cryostat	0.12	2	50	75	1	4	1200	ACC
CP	MCOXF / MCOSXF	LHC UL & UJ	IT cryostat	0.12	2	50	75	1	4	1200	ACC
CP	MCDXF / MCDSXF	LHC UL & UJ	IT cryostat	0.12	2	50	75	1	4	1200	ACC
CP	MCTXF	LHC UL & UJ	IT cryostat	0.12	1	50	75	1	4	600	ACC
CP	MCTSXF	LHC UL & UJ	IT cryostat	0.12	1	50	75	1	4	600	ACC
11 T trim		LHC RR	11 T cryostat	0.25	1	50	80	2	2	640	ACC
11 T Dipole	MBH	LHC UA	LHC DFBA	Re-use of existing DC cables							
Q4	MQYY	LHC RR	RR (DFBL)								
Correct Q4	MCBYY	LHC RR	RR (DFBL)								
Q5	MQY	LHC RR	RR (DFBL)								
Correct Q5	MCBY	LHC RR	RR (DFBL)								
Q6	MQML	LHC RR	RR (DFBL)								
Correct Q6	MCBC	LHC RR	RR (DFBL)								

17.2.12 Optical fibre infrastructure

The optical fibre infrastructure provides optical fibre links across the CERN site, including in-between surface and underground buildings. The infrastructure is also distributed in each of the LHC service areas and along the LHC arcs. This infrastructure services a variety of systems (Cryogenics, Beam Interlock, LASS, Evacuation, Power converters, IT Network, GSM, TETRA, and others). A new portion of the optical fibre infrastructure is deployed for the HL-LHC with the same topology and installation techniques as the existing one, for each of the LHC service areas. The optical fibre capacity is dimensioned according to the received requests and calculated spare capacity in the same proportion as in the existing LHC service areas). The current requests are in a phase of studies and discussions and concern the general optical fibre infrastructure, the controls for electrical distribution network, the IT Network, the crab-cavities monitoring and the magnet cold mass monitoring. The topology of the current optical fibre infrastructure is based on a star-point distribution. For the new distribution, the topology will be mirrored from the existing infrastructure in the LHC service areas. The new distribution includes also main linking paths between the existing and the new star-points. A redundancy path to the surface is also created over the new pit. This configuration will allow creating redundancy paths for critical systems and serving locally new systems that could be added later.

17.2.13 Signal cabling

Signal cabling includes the installation of electrical cables for data transfer and control for the various user systems. It typically comprises a very large volume of cables to be installed in multiple cabling campaigns. The signal cabling definition and installation for the users is outside the WP17.2 scope and is included in the scope of the different work packages. However, the resources required to supervise the signal cabling is included in the WP17.2. The signal cables are grouped together on the same cable ladder independently of the systems they serve. The vast majority of the signal cables are screened, which limits crosstalk and electromagnetic interference. Cables for those systems that are particularly sensitive to those effects are pulled on a separated cable ladder. The requested connectors are mounted at each end and then protected from dust. Each installed cable is visually checked and tested for insulation and continuity and the wiring convention is verified.

17.3 Cooling and ventilation

17.3.1 Framework for cooling and ventilation installations

The Cooling and Ventilation installation at Point 1 and Point 5 are mostly the same. The only difference between the two installations consists in the heating solution for the air-handling units: at Point 1 (in Switzerland) electrical heaters are not allowed. A dedicated extension of the superheated water network is used instead. At Point 5 (in France) there is no superheated water network, and the national law allows electrical heaters and this solution has been used here.

The design of the CV installation is done according to the 2016 user-load input data. A recent revision of the user-load requirement will be subject to an update of the cooling and ventilation system.

17.3.2 Primary water cooling

A new 3-cell cooling tower (n + 1 redundancy) of 5 MW each will be installed at each Point. The total cooling power requirements are listed in Table 17-8. The water supply temperature will vary between 20°C and 25°C. The primary water flowrate is based on 8 K temperature difference between supply and return. Three circuits will distribute the primary water in a duty and standby (1 + 1) arrangement. The pump heads are selected to provide approximately 300 kPa (3 bar) at the connexion point of each user equipment. The new plant room will house the three couples of redundant pumps, the sand filtration, and frost protection systems. The pipeline will be made of stainless steel and distributed in the various buildings using technical galleries. The water treatment station is located in a special chemical container to limit the risk of pollution.

Table 17-8: Overall cooling power requirements at Point 1

Location	Final user	Cooling power (kW)	User total (MW)	Design (MW)
UW	Power Converters Water-cooled cable Machine protection RF IOTs, drivers, circulators HV power supply Cryogenics	272 (205) 420 (420) 78 (0) 664 (352) 184 (424) 70 (50)	1.7 (1.5)	1.94*
SHM, SD	Cryogenics	5200 (5200)	5.2 (5.2)	6.0*
SU	Chillers	950 (587)	1.0 (0.6)	1.0

*: Including 15 % of margin

(xxx): Revised estimate

The general P&ID schematic of the cooling installation of the HL-LHC (LHCF31990027) is presented in the Annex of this document. Figure 17-5 shows the corresponding water-cooling architecture.

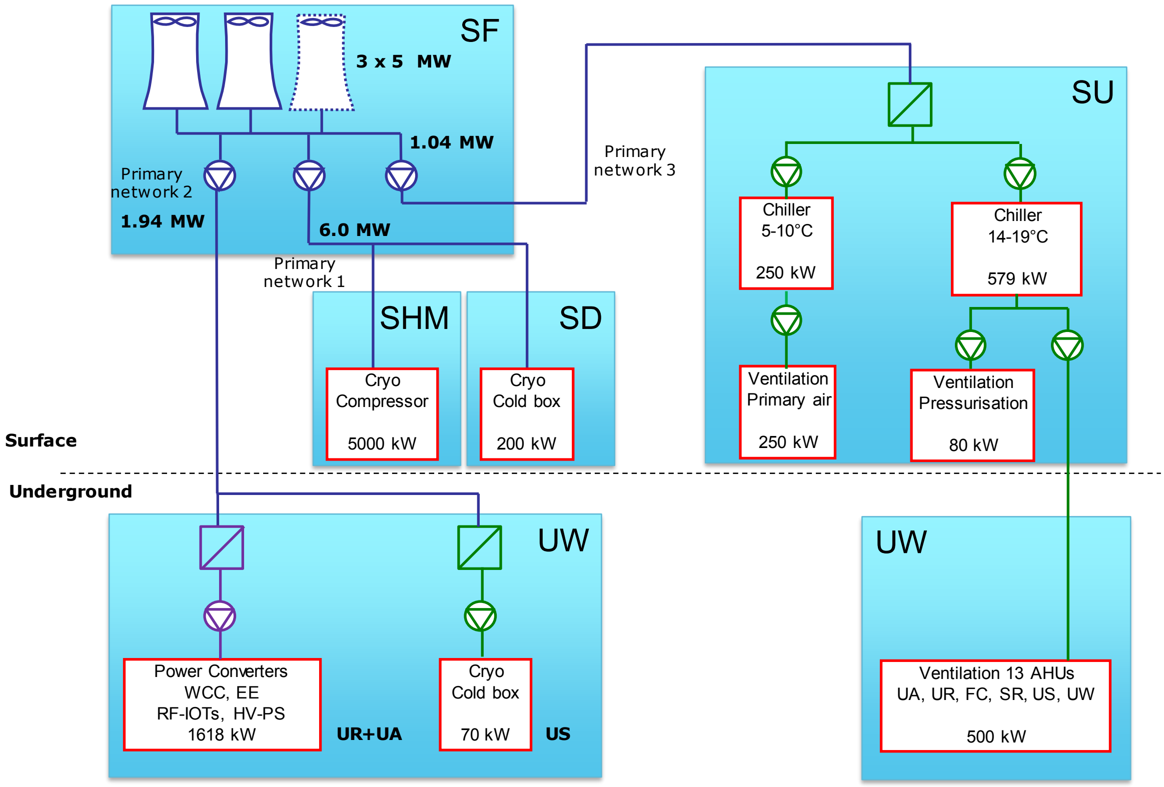

Figure 17-5: Water cooling architecture

17.3.3 UW secondary water cooling

The cold compressors of the cryogenic system are cooled by a dedicated raw-water cooling station in the UW cavern part. It will include a heat exchanger of 80 kW and a duty and standby pump.

One demineralised water-cooling circuit is installed to service all the underground installation. It will cool the power converters, the machine protection system, the water-cooled cables in the UR and the IOTs RF system in the UA. The station will include one heat exchanger (1.75 MW), a duty and standby pump and a demineraliser. The water conductivity is maintained below 0.8 µS/cm.

17.3.4 Chilled and mixed water

The chilled water production plant is dedicated to the fresh air treatment only because of its de-humidification needs. It will be located in SU17. The mixed-water production plant is also located in SU17. Table 17-9 gives the number, the unit capacity, the operating temperature, and the buffer-tank volume of the chillers as well as the distribution pump number and distribution pipework inner diameters. The pipework is in stainless steel thermally insulated.

17.3.5 Hot water for air handling units (Point 1 only)

The CERN Meyrin superheated water network is available close to the HL-LHC site. A hot water production station is installed to distribute hot water to the air-handling units located in the surface building of the HL-LHC complex at Point 1. Electrical heaters will guarantee heating power at Point 5 instead.

Table 17-9: Chiller cooling circuit characteristics

Production plant	Chiller number	unit capacity (kW)	Buffer tank volume (m^3)	Supply temp (°C)	Return temp (°C)	Distribution pump number	Distribution pipe diameter (mm)
Chilled water for fresh air handling units	2*	310 (200)	3	6	12	2*	DN80
Mixed water for surface air handling units	3*	430 (200)	5	14	20	2*	DN80
Mixed water for underground air handling units						2*	DN125

*: including 1 unit in standby for redundancy

(xxx): Revised estimate

17.3.6 Firefighting network

A firefighting water pipe is installed in the PM for the underground areas. A surface and underground firefighting water network (DN100) is installed to supply hose reels and firefighting Storz-55 connections. The network is connected to the existing firefighting networks at Point 1 and Point 5 which are supplied by the raw water pipework embedded in the LHC tunnel. At Point 5, the two rising pumps (in duty and standby configuration) located in the UJ56 shall be upgraded to increase their unit flowrate from 50 to 120 m^3/h.

17.3.7 Compressed air

The compressed air is distributed from the existing LHC network which has sufficient capacity and margin to ensure the HL-LHC needs. The compressed air network will be made of galvanised steel or stainless steel and will distribute compressed air to buildings and underground areas.

17.3.8 Clean and wastewater

A main clean water sump is located at the lowest part of the new underground areas (US) in order to collect all the infiltration or accidental water release. A duty and standby pump will lift the clean water to the surface drainage network. Secondary water sumps are located at the lowest part of the UR (Point 1 only) and of the UPRs. A duty and standby pump will lift the clean water to the main US water sump. A wastewater pit and duty and standby pumps will lift the wastewater to the surface wastewater network.

17.3.9 Underground air handling units

Figure 17-6 shows the underground ventilation architecture. Table 17-10 gives the main characteristics of the air-handling units of the underground areas including the ambient temperature range to be maintained, the total cooling capacity to be installed, the number/flow-rate/size/location of the ventilation units as well as the diameter of the supply/return ducts. The air supply and return ducts have regular spaced duct mounted grids. The underground air-handling units use mixed-water produced by the chillers located in the SU building and they are not fitted with any heating battery. For the UR, the ventilation system consists of six ventilation units located as close as possible of the equipment generating the heat load. These UR units will not be equipped with ducts, they will recirculate the air locally taking the warm air from the top part of the tunnel and supplying cold air at the level of the floor.

The two Faraday cages located in the US and in the UR have two dedicated air-handling units (one duty and one standby unit for redundancy). Some fresh air is directly supplied into the cages for hygienic purpose. The safe room located in the US has two dedicated air-handling units (one duty and one standby unit for redundancy). The two units are physically located in two different fire-compartments (one in the US and one in the UW part of the cavern). The hydrogen potentially produced by the batteries in the safe room is continuously extracted and diluted in the main ventilated US/UW volumes. The over pressurisation will be ensured.

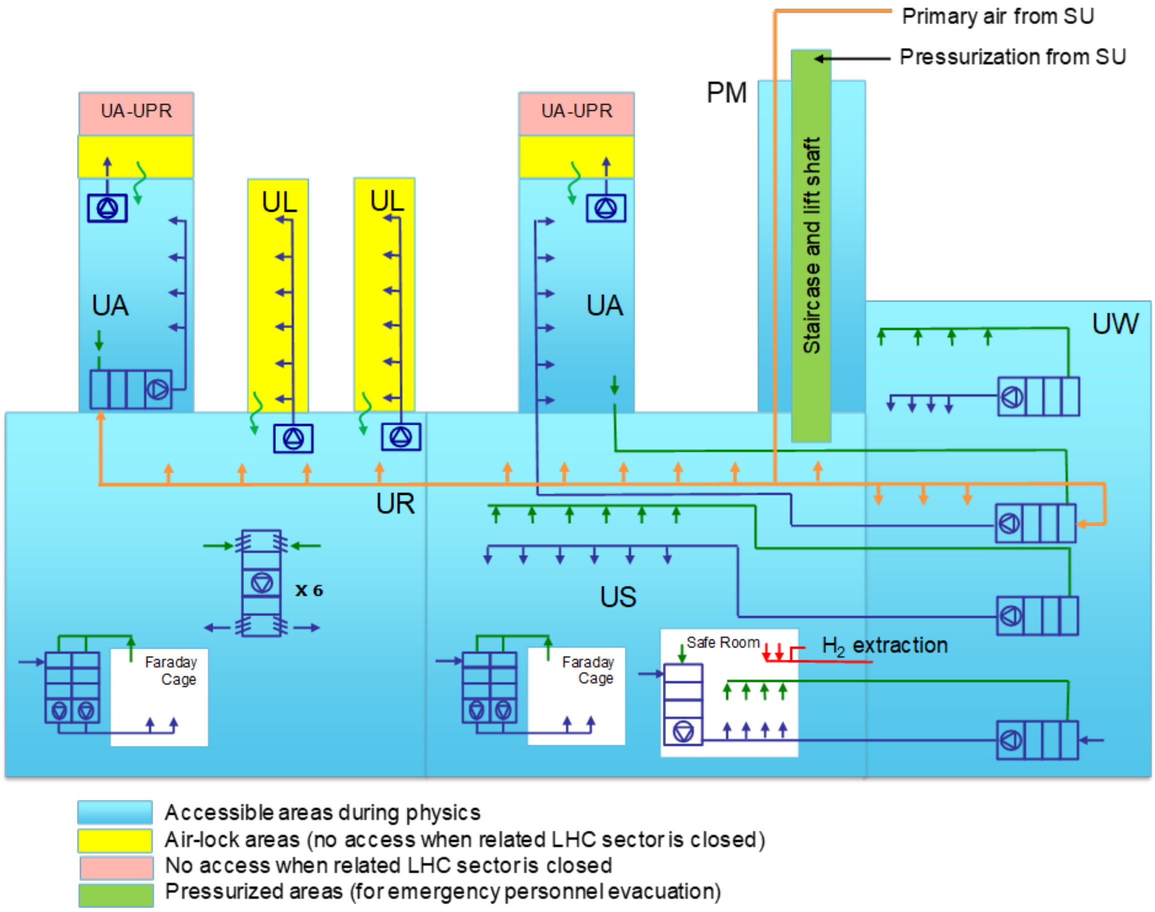

Figure 17-6: Underground ventilation architecture

Table 17-10: Underground air-handling-unit characteristics

Ventilated area	**Temp range (°C)**	**Total cooling capacity (kW)**	**Units**	**Unit flow-rate [m3/h]**	**Unit size Lxlxh (m)**	**Unit location**	**Cooling water type**	**Supply/return duct diameter (mm)**	**Supply air temp (°C)**
UR	14-25	190 (164)	6	8'500	1.65 x 1.35 x 3.5	UR	Mixed	n/a	
UAx3	14-25	60 (52)	1	11'000	5.0 x 2.6 x 1.65	UAx3	Mixed	630	
UAx3 **		0 (4)				UAx3			
UAx7	14-25	60 (52)	1	11'000	5.0 x 2.6 x 1.65	UAx7	Mixed	630	
UAx7 **		0 (4)				UAx7			
US	14-25	47 (32)	1	9'500	4.0 x 1.65 x 1.65	UW	Mixed	630	
UW	14-25	15 (7)	1	3'000	3 x 1.35 x 1.2	UW	Mixed	400	
US Faraday cage	20-22	8 (7)	2*	2'500	1.35 x 0.85 x 2.5	US	Mixed	400/350	15
UR Faraday cage	20-22	8 (7)	2*	2'500	1.35 x 0.85 x 2.5	UR	Mixed	400/350	15
Safe room	18-23	10 (7)	2*	1'500	1.35 x 0.85 x 2.5	US-UW	Mixed	400/200	16

*: including 1 unit in standby for redundancy
** behind mobile shielding
(xxx): Revised estimate

17.3.10 Primary-air distribution

The primary-air is distributed either to the underground air-handling units or directly to the rooms (see Figure 17-7). The primary air is distributed by one duty and one standby air handling unit located in the SU. Table 17-11 gives the main characteristics of the corresponding air-handling units including the unit cooling capacity to be installed, the number/flow-rate/size/location of the units, the air dew-point temperature to be guarantee, the expected dehumidification rate, as well as the diameter of the supply duct, which has to be thermally insulated. For cooling, each unit uses chilled water produced by the chillers located in the SU building. For heating, two hot water batteries (Point 1) and electrical heaters (Point 5) are implemented. The air-intake and supply ducts are thermally insulated.

Table 17-11: Primary air-handling-unit characteristics

Location	**Unit cooling capacity (kW)**	**Units**	**Unit flow-rate (m^3/h)**	**Unit size Lxlxh (m)**	**Cooling water type**	**Supply duct*** inner diameter (mm)**	**Fresh air dew-point (°C)**	**Dehumidification rate (kg/h)**	**Heating** capacity (kW)**
SU	200 (200)	2*	16'000	5.0 x 2.0 x 1.65	Chilled	800	12	80	2 x 120

*: including 1 unit in standby for redundancy
**: hot water at P1 and electrical heater at P5
***: thermally insulated
(xxx): Revised estimate

17.3.11 Staircase, lift shaft and air-lock pressurization

The PM staircase and lift shaft must be permanently over-pressurized in order to guarantee a safe evacuation of personnel in case of fire or ODH alarm. In addition, air-lock areas must be over-pressurized at 25 Pa with respect to the LHC tunnel and the HL-LHC galleries in order to guarantee that contaminated LHC tunnel air is not entering the new HL-LHC areas, which are in personnel access mode during physics. Table 17-12 gives the main characteristics of the pressurization systems (see Figure 17-7). Duty and standby units located in the SU insure the safe pressurisation including the lift exit in the US (see Figure 17-7). Both units will be equipped with a hot water battery (Point 1) or an electrical heater (Point 5). Only one of them is fitted with a mixed-water battery produced by the chillers located in the SU. The air-intake and supply ducts are thermally insulated. Two redundant ventilation systems assure the pressurisation of the airlock installed at the end of the UA galleries. The units will take air from the UA tunnel to pressurise the air-lock areas. On the same principle, two redundant ventilation systems assure the pressurisation of the airlocks installed in the UL galleries.

Table 17-12: Pressurization system characteristics

Location	Unit cooling capacity (kW)	Units	Unit flow-rate (m^3/h)	Unit size Lxlxh (m)	Cooling water type	Supply duct*** diameter (mm)	Unit heating** capacity (kW)
Staircase SU duty unit	75 (60)	1	12'000	5.0 x 2.0 x 1.65	Mixed	800	130
Staircase SU standby unit	n/a	1	12'000	5.0 x 2.0 x 1.65	n/a		130
UAx3 air lock	n/a	2*	200		n/a	n/a	n/a
UAx7 air lock	n/a	2*	200		n/a	n/a	n/a
ULx3 air lock	n/a	2*	1000		n/a	250	n/a
ULx7 air lock	n/a	2*	1000		n/a	250	n/a

*: including 1 unit in standby for redundancy
**: hot water at P1 and electrical heater at P5
***: thermally insulated
(xxx): Revised estimate

17.3.12 Heating, ventilation, and air-conditioning (HVAC) for surface buildings

The required outside fresh air will be provided by the ventilation systems in all the surface buildings. Figure 17-7 shows the architecture of the ventilation in the surface buildings. Table 17-13 gives the characteristics of the HVAC for the surface buildings including the building volume, the temperature range to be maintained, the required cooling/heating capacity, the number of units, the unit flow-rate and size, as well as the supply/return duct inner diameter. 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 will be released using several static exhausts (or louvered penthouse) located on the roof.

In the SHM building, the air return duct has regularly spaced duct mounted grids. The air supply is distributed through low velocity displacement units located on the ground floor level. The SE building is divided in two parts for the low voltage (LV) and high voltage (HV) electrical equipment. On the LV side the air supply is distributed under the false floor, the return air is taken from the top of the room. On the HV side the air is extracted from the top of the room; heat-pumps (Pt1) or heaters (Pt5) assure a minimum temperature inside both rooms. In the SF building, the air supply duct has regularly spaced duct mounted grids. The air return is done in bulk directly in the mixing plenum. In the SU building, the air return is done in bulk from the top of the room. The air supply is distributed through low velocity displacement units located on the ground floor level. This building houses as well the air-handling units for the ventilation of the SD, for tunnel primary fresh air, for the pressurisation of the staircase and lift shaft and one air-handling unit for the air heat recovery. Finally, in the SD building, the air supply and return ducts have regular spaced duct mounted grids.

Table 17-13: HVAC characteristics of surface buildings

Location	Building volume (m^3)	Temp range (°C)	Total cooling capacity (kW)	Units	Unit flow-rate (m^3/h)	Unit size Lxlxh (m)	Cooling water type	Supply/return duct diameter (mm)	Unit heating** capacity (kW)
SHM	7'125	18-26	200 (200)	1	60'000	9.0 x 3.0 x 6.0	free cooling	1350	200
SE HV room	1000	18-35	0 (0)	2*	2'500	1.2 x 1.35 x 3.0	free cooling	n.a.	10
SE LV room	500	18-35	11 (19)	2*	11'000	1.35 x 0.85 x 2.5	free cooling	n.a.	10
SF	1'600	18-35	30 (25)	1	15'000	5.0 x 1.65 x 2.0	free cooling	800/600	16
SU	6'006	18-30	47 (53)	1	34'000	5.0 x 1.65 x 2.0	Mixed and free	1'000	28
SD	3328	18-35	10 (10)	1	12'000	4.0 x 1.65 x 1.65	free cooling	710	26

*: including 1 unit in standby for redundancy

**: hot water at P1 and electrical heater at P5

(xxx): Revised estimate

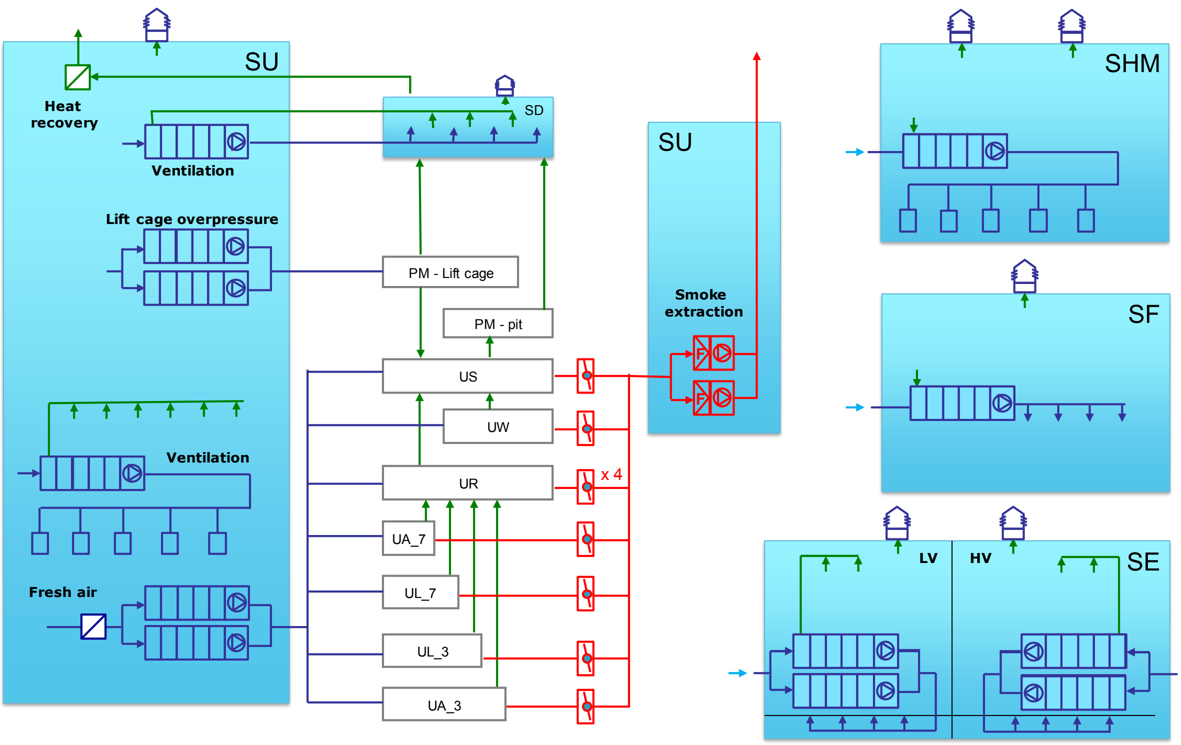

Figure 17-7: Ventilation architecture of surface buildings and smoke extraction

17.3.13 Smoke extraction

Each of the buildings SHM, SU, SD, SE and SF are equipped with a dedicated and independent smoke extraction system. The smoke extraction is ensured by natural ventilation using dedicated sky domes. The free opening areas will respect 1/200 of the floor area of each building. Mechanical air intake dampers are installed in addition to the access doors where needed in order to have less than 10 meters without an air intake entry. The static exhaust(s) and air intake damper(s) will be operated using a firemen cubicle located at the entrance of each building.

Two fans of 36000 m^3/h each are installed out of the SD to assure the smoke extraction form the underground buildings. The fans are F400 120 rated (according to EN 12101) and hardwired to the SMSC (Système de Mise en Sécurité). The fresh air intake comes naturally from the PM shaft. In addition, motorised fresh air dampers are installed in the SD to facilitate the fresh air entry into the shaft. A calcium silicate duct rated REI90 600°C in multi-compartment sections and RE90 600°C in single-compartment sections collects the smoke in the underground buildings. A fire-resistant door is installed in the middle of the UR galleries; the door is motorised and opens to assure the fresh air intake in some smoke extraction scenarios. Smoke curtains are installed in various positions on the vault of the gallery to define smoke retention areas. Smoke resistant dampers are installed in the ductwork in the appropriate locations to allow the extraction of the smoke in the targeted area. Figure 17-7 shows the smoke-extraction architecture.

17.4 Access and alarm systems

17.4.1 Objective

The HL-LHC project includes many modifications to the current LHC installations. On the one hand, large new surface buildings will be constructed and new underground areas excavated for the new equipment, and, on the other hand, existing LHC equipment will be upgraded, such as the inner triplet areas of Point 1 and 5. New types of equipment (e.g. crab cavities) as well as higher prompt and residual radiation levels due to the increased luminosities around interaction points require a re-evaluation of risks around these sections of the LHC tunnel. The new underground areas must be constructed so as to fulfil the regulations for fire and radiation safety as well as for oxygen deficiency hazards.

This Section enumerates the modifications to the current LHC access and safety systems (LASS/LACS) including integration of the new underground installations at LHC Points 1 and 5. It contains also the modifications and new installations of alarm systems and other associated safety systems. All alarm systems send Level-3 alarms to the fire brigade for immediate interventions via the CERN Safety Alarm Monitoring system (CSAM). Table 17-14 gives the synthesis of the estimates for the principal safety, access, and alarm equipment by system.

17.4.2 Requirements and constraints

Installation of safety and access systems poses no particular environmental concerns. The LHC is a CERN Beam Facility, and as such, the provisions laid out in the November 15th, 2010 tripartite agreement in matters of radiation protection and radiation safety fully apply. Namely, the LHC personnel safety systems are subject to joint inspection visits by the competent Host State authorities. Safety document "CERN Safety Code E – Fire protection" specifies that installed equipment shall follow the regulations of the host states on their respective territories. In order to treat the LHC and the HL-LHC as a whole, a formal derogation will be put in place to treat the HL-LHC as a French installation for this purpose.

Access and safety systems are designed to be operational constantly 24/7, with the exception of clearly defined maintenance windows. During maintenance, the installed systems may need to be accessed and access control functionality replaced by temporary measures, as applicable. During normal operation, these systems are for the most part operated remotely, but may require underground access for corrective actions. The safety report "Emergency Preparedness of the HL-LHC Underground Service Areas" [3] defines the precise needs in terms of safety functions and safety systems.

Access and safety systems may be sensitive to single event upsets caused by LHC operation and to degradation due to high radiation fields. For these reasons, all equipment not required close to high radiation areas, must be located at a safe distance from such areas. High magnetic fields can cause magnetic locks and electric motors to malfunction. Therefore, all access doors should preferably be located at a safe distance from magnetic fields. All safety and access systems require their own control cabling between the equipment and the control racks. This cabling is to be installed within dedicated safety cables trays, as is the case in the LHC.

In addition, the LACS and CSAM require network connectivity via the CERN Technical Network, which must be present close by so as to only require connection via an Ethernet patch cable.

Table 17-14: Synthesis of the estimates for the principal safety, access, and alarm equipment by system (total quantity for the 2 Points)

Equipment	System	Q
Interlocked end-of-zone door (grating) in the UL	LASS	4
Interlocked end-of-zone/ventilation door (solid) in the UA	LASS	4
Interlocked sector door (grating) in UPR	LASS	4
Supervised ventilation/overpressure door in the UPR	LASS	4
Interlocked ventilation door in the UL	LASS	4
Interlocked ventilation door in the UA	LASS	4
Key-operated switch box for arming patrol in a sector (UA, UL, UPR)	LASS	16
Equipment rack for cabling, relays, PLC I/O modules	LASS	4
RF EIS : Elements acting on RF powering	LASS	4
Personnel Access Device (PAD) including iris scanner	LACS	2
Material Access Device (MAD) including video surveillance	LACS	2
Equipment rack including badge readers, interphone, panel-PC	LACS	2
Access point video surveillance camera	LACS	4
Non-interlocked but supervised door at top of pit	LACS	2
Fire detector	Fire Detection	220
Fire central concentrating several detectors	Fire Detection	4
Red telephones (direct line to the fire brigade with alarm)	Emergency Comm	50
Secure communication equipment (TETRA)	Emergency Comm	2
CSAM rack: Secure delivery of level 3 alarms to the fire brigade	CSAM	2
ODH detector and warning	ODH Detection	74
ODH central	ODH Detection	6
Evacuation siren in underground areas	Evacuation	40
Evacuation central	Evacuation	2
CROME monitoring station for detection of ambient radioactivity	Radiation Monitoring	8
Alarm unit for CROME monitoring station	Radiation Monitoring	8
Simple access-controlled door	SUSI	24
Non-access controlled but supervised door (emergency exit)	SUSI	12
Video surveillance camera of the buildings and sites	SUSI	30

17.4.3 Power distribution

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

17.4.4 Access safety system

The LHC Access Safety System (LASS) is the main safety system ensuring personnel safety in the various operational modes of the LHC (e.g., general access, commissioning, powering, beam operations). The LASS consists of two diverse and redundant safety chains for the critical operations. The main safety logic is implemented using Siemens safety PLCs. Interlocking of the exterior envelope is also doubled by a redundant cabled loop using relay-based logic in order to ensure that no intrusion into the controlled areas can go unnoticed even in case of a potential unsafe failure of the PLC equipment. The HL-LHC requires the new important safety elements (EIS) to be installed into the LHC tunnel and the access galleries include access safety elements (EIS-a) as well as machine and optional beam safety elements (EIS-m and EIS-f, respectively). EIS-a consists of access doors and patrol boxes. Concerning the access doors, the instrumentation and controls of the doors are part of the WP17.4 scope; the supply and installation of the doors are part of the WP17.10. Figure 17-8 shows the underground access zoning and access elements. The cabling of the new EIS to the LASS site PLC is implemented directly via existing pathways in the LHC (EIS-a/m) and possibly via the new HL-LHC service areas (EIS-m). If a connection via the HL-LHC service areas is eventually required, a LASS rack with remote I/O units connecting to LASS site PLCs will be installed on the surface of the new HL-LHC access pits (PM17 and PM57). The total number of elements to be installed at the two sites is:

- 8 interlocked end-of-zone doors to isolate the LHC tunnel and service areas from the new HL-LHC underground galleries (UA, UL). Due to lack of space in the UA galleries, the end-of-zone doors there will also serve as ventilation doors (solid construction), whereas in the UL galleries they are of grating type.
- 4 interlocked sector doors to isolate the LHC tunnel from the UPR safety exits. These sector doors are of grating type and are installed at the lower parts of the UPR. They include opening devices and patrol boxes on both sides.
- 4 interlocked ventilation doors in the UL galleries.
- 4 overpressure doors in UPR galleries giving towards the LHC tunnel and in series with the sector doors. These doors are interlocked by the powering interlock (PIC) during the powering phase II and simply supervised with alarm during beam.
- 4 interlocked ventilation doors in UA galleries.
- 8 individual patrol boxes at suitable locations according to new zoning (UA, UL, UPR).
- EIS for the RF of the crab cavities. The exact type and number of these elements will depend on the risk analysis.

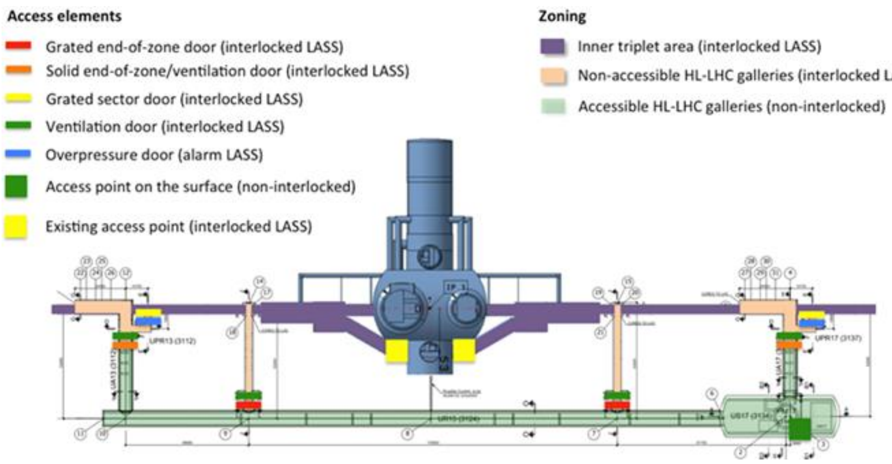

Figure 17-8: Underground access zoning and access elements at Point 1. Zoning of Point 5 will be similar as applicable with the exception of existing access point and service tunnel locations.

17.4.5 Access control system

Concerning underground access, the LHC Access Control System (LACS) manages access to the controlled areas according to access modes given by the LASS. The LACS reads the user badges, checks the access rights, verifies the user identity via biometric check, and lets the user pass if all access 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 token will 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 will be of non-interlocked type, which means that no safety tokens are necessary. The equipment to be installed in the LACS access points at PM17 (building SD17) and PM57 (building SD57) are the Personnel Access Device (PAD) including the iris scanner and the Material Access Device (MAD) including video surveillance and personnel detection inside the MAD. In addition, LACS equipment rack at the access point includes badge readers, intercoms, and a panel-PC for information display, but without a safety key distributor. A video surveillance is available both on the outside and inside of the access points. Finally, a supervised, but non-interlocked, access door provides a second emergency evacuation path from the top of the pit.

Access control in the surface buildings is implemented via the SUSI system, which comprises badge readers and video surveillance both inside and outside of the buildings.

17.4.6 Automatic fire detection system

The Automatic Fire Detection (AFD) system consists of detectors of various kinds (point detectors and/or air sampling networks), located in specific areas to detect the presence of smoke. These detectors are connected to Control and Indicating Equipment (CIE) located in one of the surface buildings. If a fire or smoke hazard is detected, the CIE generates Level-3 alarms and launches automatic safety functions. Fire detection is installed in all underground areas. The UR gallery will be equipped with smoke curtains designed to divide the gallery into zones that can contain smoke from a localized fire until smoke extraction can be activated on that zone. Fire detection is also installed in all surface buildings. A reservation is made for an optional installation of fire detection also in the inter-building technical galleries.

17.4.7 Emergency telephones

The underground areas will be equipped with emergency telephones (so-called red telephones) at regular intervals (~70 m), which provide a level-3 alarm and a direct telephone connection to the fire brigade.

17.4.8 CSAM and MMD

The CERN Safety Alarm Monitoring system (CSAM) is the primary safety system for delivering level-3 alarms to the CERN fire brigade. The LSAC (Local Safety Alarm Controller) PLC receives all the relevant Level-3 alarms within that area and delivers them to the fire brigade via diverse and redundant signal chains. The MMD (Multi-purpose Monitoring Device) is used to deliver alarms of level-2 and below directly to the TI operators via TIM. The CSAM and MMD systems include the cable infrastructure required to connect all Level-3 alarms to CSAM and other alarms to MMD. To accommodate the new alarms, the acquisition capacity of these systems at Point 1 and Point 5 will need to be increased.

17.4.9 TETRA and GSM

The TETRA secure communication system is installed and maintained by IT/CS. However, certain alarms from the TETRA system are transmitted via the CSAM system. As the TETRA uses the same infrastructure as the standard CERN GSM network (leaky feeders), the GSM infrastructure will be installed at the same time.

17.4.10 Automatic ODH detection

The Automatic ODH detection system consists of oxygen sensors located in specific areas to detect an oxygen deficiency due to a gas release. These sensors are connected to a Control and Indicating Equipment (CIE). If an ODH is detected, the CIE generates Level-3 alarms and launches automatic safety functions, automatic emergency evacuation, and ODH flashing lights. In the new underground areas, ODH detection is installed in the service caverns (US) as well as in the galleries UR, UA, UL, and UPR. ODH sensors are installed approximately at every 50 m in linear galleries and according to need in more complex spaces. ODH detection is to be installed in the head shaft building (SD) housing the cold boxes, in the compressor building (SHM) as well as in the inter-building technical galleries.

17.4.11 Radiation monitoring

As the accessible non-interlocked areas of the underground HL-LHC galleries are adjacent to some of the most radioactive areas of the future HL-LHC beam line, online monitoring of radiation is required at the end-of-zone doors of the interlocked zones. 4 CROME monitors with associated alarm units will be installed per site in the immediate vicinity of the end-of-zone doors in the UA and the UR next to the UL galleries.

17.4.12 Automatic protection system

The 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 of triggering these functions remotely from CCC or SCR and the possibility to sound safety instructions to the HL-LHC area remotely from CCC and SCR.

17.4.13 Evacuation system (safety sound system)

The emergency evacuation system is a part of the automatic protection system. It consists of audible evacuation signals triggered either automatically by another safety system or manually by pushing one of the evacuation buttons installed within the area in question. The evacuation system is to be installed in all underground areas.

17.5 Monitoring and operation of general services

17.5.1 Objective

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 TI 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, as applicable. This Section describes the general monitoring framework of TIM, into which the various subsystems are to be connected and the installation of standard network services.

17.5.2 TIM infrastructure adaptations

While TIM is capable of connecting to many different equipment and existing SCADA systems to access data of various types, it is always possible that some application-specific development to the core system will be necessary to fully support the control system to be connected to TIM.

17.5.3 Subsystem configuration and development

The main bulk of work consists of the owners of various HL-LHC subsystems to set up monitoring of the important parameters of their systems in such a way that they can be read by TIM data acquisition modules. The following steps are necessary for setting up TIM monitoring of a device:

- Definition of the monitored device variables and making them available for readout via network.
- Definition of the tags in the TIM system to correspond to the variable to read. This step consists of defining a hierarchical tag name corresponding to the device in question, defining the data acquisition method and address, and defining the operator action in case of an alarm.
- Building TIM graphical visualization based on the registered tags.

Setting up of monitoring of the devices belonging to the various equipment groups is carried out in collaboration with the equipment group in question and the TIM team.

17.5.4 Networking

Networking will be 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 is provided. This requires installation of a Starpoint rack at approximately every 70–80 meters. As the UPR has to be operational before the deployment of the networks inside the HL-LHC galleries, dedicated UPR networks are deployed from the LHC tunnel.

All surface buildings will have cabled connections at regular distances. Wi-Fi coverage will be limited to the more frequented areas (control rooms, rack areas, etc.).

17.6 Transport

17.6.1 Objective

The scope of transport covers the surface transport & handling, the transfer to the underground facility and the transport & handling in the tunnels and caverns.

This Section lists the new transport and handling equipment that will be required in the new facilities for HL LHC installation. This document does not include anything concerning the dismantling and installation of components in the existing LHC facilities.

17.6.2 Requirements and constraints

The supply, including the installation, shall comply in all respects with the CERN safety rules. The CERN safety rules are available under the Refs. [6][7] and [8].

As for the LHC, the tight schedule and the large quantity of items to be transported will require fully integrated logistics for the transport on the surface and even more stringent co-ordination underground. The general means of transport and handling of equipment, together with the organisation necessary to bring the equipment to its final destination is directly inherited from LHC.

Articulated vehicles with hydraulic suspension are used for the road transport. The ROCLA vehicles are used to transport the cold masses and cryomagnets in SM18 and SMA18. Mobile cranes (CERN or externally rented) is used to install big elements such as helium tanks and transformers. Exceptional transport is rarely used and is done via one of CERN specialised contractors.

Two temporary storage platforms (including in the WP17.9 scope) are required in Point 1 and Point 5 to allow transit of equipment and for logistic reasons. The use of a heavy haulage external company is foreseen with the direct consequence of having to park on site trucks and mobile cranes with high-payloads. The pavement in these zones shall withstand a load of 300 kN/axle.

No specific requirement for new special transport equipment underground has been identified at this stage (apart from the EOT cranes in the cavern). Preliminary studies show that existing CERN transport equipment fulfils most requirements for transport underground in tunnels and galleries (electric tractors, trailers, forklifts, etc…). Detailed integration studies to define precise volume reservation for transport shall be conducted once the layout is finalized to contribute to the optimization process.

The new HL-LHC infrastructures are designed in a way that workers involved in transport and handling operations cannot be exposed to the risk of exposure to ionising radiation.

17.6.3 Lifts

The specifications are based on LHC 3-t lifts (e.g. PM54, and PM15); the capacity / dimensions of these lifts cover 90% of transport requirements. The safety requirement covers LHC specific risks (over pressurized shafts in case of fire or He leak) and they will be fed by UPS and have a safe level-3 communication with the fire brigade so that they will be used as evacuation exits in case of incident in the underground facility. The lifts components will be the same as for LHC lifts (the 6 LHC 3-t lifts will be replaced by 2021) for improving availability (common spare parts, better training/performance of maintenance services). No specific constraints of dimensions or any specific additional requirements with respect to LHC lift have been identified at that stage. Table 17-15 gives the main lift characteristics. The lift concrete casing will be equipped with periodic grating doors for access.

Table 17-15: Main lift characteristics

Location	**Capacity (kg)**	**Travel Height (m)**	**Door width (m)**	**Door height (m)**	**Speed (m/s)**	**Cabin dimensions (m)**		
						Length	**Width**	**Height**
PM17/57	3000	72.5	1.9	2.7	1.6	2.7	1.9	2.7

17.6.4 Electric travelling cranes

The overhead cranes preliminary design 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 17-16 list the cranes main characteristics. For more detailed information (e.g. reactions on rails) please refer to the general layout drawing of each building.

Table 17-16: Main overhead travelling cranes

Location	**Capacity (t)**	**Height Hook (m)**	**Lifting Height (m)**	**Hopper (m)**		**Speed (m/min)**	
				Rail length	**Span**	**Max**	**Min**
SHM17 / 57	20	6	6	50	15	5	0.25
SD17 / 57	25	10	100	28.4	16.1	20 (without load) 10 (with load)	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

17.6.5 Manual overhead travelling cranes

All UA galleries will be permanently equipped with manual overhead travelling (MOT) cranes travelling on rails to allow for handling and transport of the RF components. Table 17-17 gives the characteristics of the UA cranes.

In both Points 1 and 5, one UL gallery will be permanently equipped with manual cranes travelling on rails to allow for handling and transport during maintenance of cryogenic components. Table 17-17 gives the main characteristics of the UL MOT cranes.

Table 17-17: MOT crane characteristics

Location	**User**	**Capacity (t)**	**Length (m)**	**Width (m)**
UA13 / 17 / 53 / 57	RF	1	26	5
UL17 / 57	Cryogenics	1	12	2

17.6.6 Hoists

Water sumps are equipped with heavy lifting pumps that need to be maintained. The supports for the hoist are permanently installed on site. Only one hoist unit is requested, that will be 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 tremie with a dedicated 500 kg hoist will be permanently installed to lift the tools and consumables to the US top floor that communicates with the UW top floor through a door in the separation wall.

In the SHM buildings, a hoist on a rail is required to transfer the load in the second bay of the building. Table 17-18 gives the hoist characteristics in the different location

Table 17-18: Hoist for the lifting pumps of the water sumps

Location	User	Capacity [t]
US17 / 57	Cooling & ventilation	0.5
US-UW17 / 57	Cooling & ventilation	0.5
SHM17 / 57	Cryogenics	1.5

17.6.7 Drawbridges

For installation of the large cooling & ventilation equipment's and all heavy equipment's located in the UW upper floor, two 5-t drawbridges will be permanently installed inside the shaft of the US caverns in point 1 and 5. (They are kept in vertical position closed during normal operation. When equipment needs to be transported to the UW upper floor, the drawbridges are lowered in the loading bay open and provide a platform that is accessible with the SD building cranes.)

17.6.8 Shielding

All UA galleries will be equipped with 12-t mobile-shielding doors with electrical motors. The dimensions (based on preliminary studies) are: 2 m x 0.8 m x 2.8 m. The ground rails are not included and are provided by WP17.1. In addition, 102 t of steel and 48 t of concrete blocks are used in the construction of shielding walls in the UL galleries.

17.6.9 Tooling for transport

Special tooling is required for cold box handling, QRL sections, electrical racks, etc… No specific requirement for special transport vehicle has been identified yet at this stage. The necessity of special vehicles or trailers be for sure appear in the detail design phase.

17.6.10 Studies

The following Computer Aided Design (CAD) studies shall be conducted for simulation of transport scenarios, for integration studies to define precise volumes reservation for transport and for the design of new tooling and special equipment's (e.g.: lifting beam, supports, etc…).

17.7 Logistics and storage

17.7.1 Objective

The HL-LHC project will bring an increase of activity in logistics services. The objective of sub-work-package 17.9 is to adapt the logistics capacity to foreseen workload coming during the project period, both in terms of FTEs and storage space.

17.7.2 Logistics services

The following services are impacted by the HL-LHC project:

- Shipping & waste: Administrative work linked to import activities (transport management from suppliers to CERN, customs clearance, VAT exoneration documentation) and waste traceability requested by the French and Swiss authorities.
- Goods Reception: CERN official order matching and registration, quantitative control, packaging control, establishment of eventual reserves and responsibilities in case of damage.
- Internal distribution: deliveries of goods and material from goods receptions and Stores to any locations at CERN and vice versa.
- Stores - Product management: Supply and demand management for standard items. Price inquiries, replenishment, order follow-up.
- Stores - Warehousing: Qualitative reception for standard items, put-away, picking.
- Storage areas**:** Operation of storage areas for radioactive and conventional materials.

The HL-LHC project planning suggested a significant increase in the logistics services from 2017 to S1/2026:

- Wastes will be generated on CERN site from the beginning of the construction.
- Increase of official orders and imports foreseen implying extra administrative work and movements in goods receptions.
- Increase of internal distributions from goods reception/Stores to CERN points. Logistic reinforcement might be necessary.
- Increase in volume for strategic standard materials from CERN Stores inducing extra work both for product management and in the warehouses.
- Extra movements foreseen in storage areas.

17.7.3 Conventional and radioactive storage

Both conventional and radioactive storage space is needed in current buildings. A new “flex” building of 10000 m^2 has been made available in 2018. The “flex” building includes both conventional and light radioactive storage space. During LS2, the building will be managed by the LS2 team, which will also include the HL-LHC activities that will take place in that shutdown. SMB department will take over the operation of the building after LS2. The shift of the LS3 is impacting the storage need as the ready-for -installation equipment shall be stored during one additional year.

Concerning conventional storage, existing buildings (897, 917 and 957, 954, SAX area), the temporary storage structures at Point 1 & 5 (see below) and the new “flex” building will offer enough capacity to cope with the HL-LHC project. The actual requested space for conventional storage consists of 2 surfaces at Point 1 and 5, each one will be between 200 to 250 m^2 (needed between LS2 and LS3). The modalities for implementation and the functional specifications are still to be defined. Two temporary storage platforms are required in Point 1 and Point 5 to allow transit of equipment and for logistic reasons. The use of heavy haulage external company is foreseen with the direct consequence of having to park on site trucks and mobile cranes with high-payloads. The pavement in these zones shall withstand a load of 300 kN/axle. Only the installation of the structure is included in the sub-WP17.9.

Radioactive storage covers only storage of radioactive equipment (e.g. spares), and not radioactive waste, which is managed by HSE-RP. For information, radioactive storage is not possible outside CERN. Table 17-19 gives the preliminary forecast for RP storage. Pallet storage is included in the figures for LS3, which will reduce the need of space.

Table 17-19: Preliminary study using forecasts collected via HSE-RP in 2015

TOTALs	Per period (m^2)	Integral (m^2)
End 2016	36	36
LS2	17.1	53.1
LS3	497.86	550.96

The existing radioactive storage buildings (954 and 955) did not have remaining floor areas before the availability of the new “flex” building. To free space, the new “flex” building allows the storage of light-radioactive equipment. The threshold for light radioactivity has been established allowing the transfer to the “flex” building of equipment equivalent to about 150 m^2. Further optimization will be needed because the available space does not satisfy yet the HL-LHC project storage need of about 500 m^2.

17.8 Operational safety

17.8.1 Objective

The scope of the operational safety is the procurement and installation of doors in the caverns and underground galleries, of smoke curtains in underground galleries, of large sectional doors for surface buildings, of fire fighting vehicles in the UA galleries, of fire extinguishers. In addition, resources for RP operational support, safety coordination and safety inspection are also included in this scope.

17.8.2 Doors and curtains

Doors and their corresponding frames are required to guarantee the sectorization, the safety and the evacuation of personnel in the caverns and underground galleries. Table 17-20 gives the characteristics of the doors included in the scope.

Table 17-20: Characteristics of doors and curtains

Type	Location	Total number	Opening size L x H (m)	CE interface size	resistant category		Comment
					Fire	Pressure	
Ventilation and fire-resistant door	UA airlock system	4	1.3 x 2.4	R 3.2 m	EI 120	n/a	
Ventilation and end-of-zone door	UA airlock system	4	1.3 x 2.4	R 3.2 m	n/a	n/a	
End-of-sector door	UPR LHC side	4	1 x 2.1	1.16 x 2.2	n/a	n/a	Grating
Fire- & pressure-resistant door	UPR LHC side	4	1 x 2.1	1.08 x 2.2	EI 120	60 mbar	
Fire-resistant door	UR	2	2.8 x 2.8	R 2.9 m	EI 90	n/a	
Fire-resistant door	UW	4	3 x 3	3.1 x 3.05	EI 90	n/a	1/3 - 2/3
Fire-resistant door	Safe-room	2	2 x 2.45	2.1 x 2.5	EI 120	n/a	
End-of-zone door	UL	4	1.1 x 2.15	R 1.6 m	n/a	n/a	Grating
Ventilation door	UL	4	1.1 x 2.15	R 1.6 m	n/a	n/a	
Ventilation and fire-resistant door	US lift sas	2	2 x 2.65	2.1 x 2.7	EI 120	n/a	
Sectional door	SD	2	6 x 6	n/a	n/a	n/a	wall mounted
Sectional door	SF	2	4 x 4	n/a	n/a	n/a	wall mounted
Sectional door	SHM	2	5 x 5	n/a	n/a	n/a	wall mounted
Sectional door	SHM (CV room)	2	4 x 5	n/a	n/a	n/a	wall mounted
Sectional door	SU	2	5 x 5	n/a	n/a	n/a	wall mounted
Smoke curtain	UR	6	n/a	R 2.9 m	EI 90	n/a	
Smoke curtain	UA entrance	4	n/a	R 3.2 m	EI 90	n/a	
Smoke curtain	UL entrance	4	n/a	R 1.6 m	EI 90	n/a	
Noise curtain	SHM	2	5 x 5	n/a	n/a	n/a	

17.8.3 Firefighting equipment

Four firefighting vehicles are located in the UA galleries on the UPR side. These vehicles are composed of a tractor and a trailer. In addition, fire extinguishers are periodically distributed in underground structures and surface buildings. Table 17-21 gives the number of extinguishers to be installed.

Table 17-21: Number of extinguishers per Point

Location		Underground	SU	SD	SE	SF	SHM	Total
# extinguishers per Point	5 kg CO_2	14	5	3	4	2	4	32
	9 kg CO_2	2	0	0	0	0	0	2

17.8.4 RP support, safety coordination and safety inspections

The radioprotection activities, like controls, transport, reception, and storage of waste, are supported via a service contract. The safety coordination supports the installation activities. During these periods, the category of the installation worksite will be "Technical Stops". The safety inspections, like electrical, crane, pressure-test inspection, are supported via a service contract.

17.9 Reference

[1] *S. Bertolasi et al*. Technical design report EN-EL for HL-LHC, EDMS: 1688633.

[2] EN-EL, "18 kV distribution HL-LHC1 project", EDMS: LHCEM_1005 rev.AA.

[3] EN-EL, "18 kV distribution HL-LHC5 project", EDMS: LHCEM_5003 rev.AA.

[4] EN-EL, "Low voltage distribution HL-LHC1 project", EDMS: LHCEB_1208.

[5] *T. Otto*, Emergency Preparedness of HL-LHC Underground Service Areas, EDMS: 1610772.

[6] Safety rules Web page.

[7] Host states http://hoststates.web.cern.ch/hoststates/en/Welcome.html.

[8] Prestations sur le site du CERN - Working on the CERN site, EDMS: 1155899.