Advanced Virgo - IME
Report to IRC

Infrastructure modifications: proposed strategy for noise reduction

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2 Subsystem overview

The IME subsystem (Infrastructure Modifications for Environmental noise reduction) concerns all the hard works aimed to reduce the level of anthropogenic noise into the experimental buildings. The main tasks of IME will be: the replacement of the machines with more silent ones and, if needed, their displacement out of the experimental halls; the improvement of the insulation performances of the air flow distribution systems; the realization of adequate acoustically insulated rooms to displace the noisy electronics (or part of it). The subsystem will also be involved in minor tasks such as the support in the realization of the eventual infrastructural works needed for the installation of the deliverables of the other subsystems.

3 Peculiarity of the IME subsystem

In order to better understand the specificity and peculiarity of the IME subsystem design with respect to the other subsystems, a few preliminary considerations have to be made.
First of all it has to be considered that, in general, when we approach the design of civil engineering works, we first establish the basic requirements of the works to be realized and then we develop the various design options to meet such requirements.
With respect to the IME project, the basic requirements are difficult to fix since the scope of the project - the environmental noise mitigation - is to be evaluated not with a view of complying with general standards or official laws, but with the future AdV interferometer sensitivity. As a consequence also cost-benefits analyses are very hard to perform.
Secondly, an important role in defining IME subsystem design requirements will be played by the result of Virgo+ environmental noise mitigation activity.
As of today, the environmental noise hunting activity has individuated the most relevant sources (the noise-inducing machines) of seismic, acoustic and electro-magnetic noise and some major noise coupling paths to the interferometer. These coupling noises are expected to be a limiting factor for Virgo+, and a few ad-hoc and low impact infrastructure modification works aimed at mitigating the noise effects have already been scheduled for Virgo+ commissioning phase.
A preliminary evaluation of the works performed seems to be encouraging, however part of the works are not completed yet and other are still under investigation. The effectiveness of such mitigation campaign has to be evaluated when all the works will be completed.
In this framework it has to be noted that the results expected from Virgo+ mitigation works can only represent a projection of the present noises on the AdV sensitivity. Considering the large amount of noises produced to the interferometer by the above mentioned sources (as better specified in the following sections of this document), we should avoid to face the possibility that not yet evidenced noise coupling could affect the AdV interferometer in the new most sensitive configuration.
A further reason of uncertainty in defining IME design requirements is then represented by the fact that as of today there are still important design solutions that could be envisaged by other subsystems/Virgo groups in relation to the AdV project, such as the thermal stability of the towers and the electric power DC distribution for the experimental halls apparatus. The implementation of such solutions would significantly affect the definition of requirements and the specifications of the air conditioning systems (HVAC systems) and the electrical power systems for AdV and, consequently, the strategy to adopt in order to reduce environmental noises.
In light of the above, at present the IME subsystem keeps open all possible strategies to approach the problem of noise mitigation and so the design questions concerning the infrastructure modification works for the reduction of the environmental noises.
The designed solutions proposed for AdV are still in a preliminary phase and mainly based on the experiences gained with regard to Virgo systems operation, the rules quoted in literature and qualitative considerations.
Therefore, the hypotheses evaluated are based on the “principle of care”. Given the heavy impact on the interferometer of the civil engineering modification works and the uncertainties of their effective mitigation effects, it is necessary to take into account significant safety margins.

Interventions “a posteriori” to be realized during the commission phase of AdV are generally more expensive, difficult to implement and require the interruption of the scientific activity.
Finally, as further point of uncertainty, we have to consider that studies of alternative strategies for tackling environmental noise and its coupling to the interferometer have started (modification of the support systems of the in-air optical benches). However the full results are not likely to be available before the AdV project approval; besides, such alternative strategies will inevitably need other infrastructure modification works.
In conclusion it has to be mentioned that the IME subsystem will be involved also in generic works as support to the other subsystems, which are not directly related to the noise mitigation, but are inevitable. Such works will concern the realization of the infrastructures needed for the installation of the deliverables of the other subsystems (i.e. modification works of the power systems to install equipments, realization of the external basements of the LN_2 tanks for the cryotraps, etc.) and their impact has been considered in the drawing up of the preliminary evaluation of costs, manpower need and planning.

4 The noise hunting activities so far

4.1 Introduction

During V/V+ commissioning the most relevant noise-inducing machines have been identified and progresses have been made in understanding the coupling mechanisms between such noises and the interferometer. The description of such activities is provided in [1].
In order to mitigate the environmental noises several infrastructure works have been performed during V/V+ commissioning.
A description of these actions is reported in [2] where are detailed, for each work, the motivation, the noise mitigation achieved, the limitations/side effects (if presents) and the residual noise. The list in the following paragraph summarizes these mitigation works and reports the main results achieved. It also reports the foreseen/useful works to be done before VSR2.

4.2 Works performed/planned for the noise mitigation

Here below is a list concerning the improvements works performed/planned so far.

nr.	item	date	notes
1	Acoustic enclosures in LL	Sep 2006	Factor 2 to 5 noise reduction above 100 Hz.
2	Acoustic enclosure for DL	Apr 2007	Factor 2 noise reduction at 50 Hz, 4 to 15 from 100 Hz to 1 kHz.
3	Acoustic enclosures for NEB optical bench	May 2007	Factor 2 noise reduction at 50 Hz, 4 to 15 from 100 Hz to 1 kHz.
4	Acoustic enclosures for WEB optical bench	May 2007	Factor 2 noise reduction at 50 Hz, 4 to 15 from 100 Hz to 1 kHz.
5	Installation of rubber bellow in the cold water pipeline to mitigate CB pump 1 noise	Dec 2007	Not much effective.
6	Installation of acoustic panels on the DAQ windows	Jan 2008	Acoustic noise transmitted to Central hall reduced by a factor2 above 100 Hz.

nr.	item	date	notes
7	Relocation of the DAQ HVAC machine	Feb-Mar 2008	Reduction of noise transmitted to Central hall in the 50-150 Hz band.
8	Realization of the EE Room (acoustic separating wall, door and cooling system) to host LL electronic racks	Jul 2008; Feb 2009	Acoustic isolation of EE Room respect to LL benches is a factor ≈100 at 100 Hz, ≈ 1000 at 1kHz.
9	Modification of the CB HVAC machine air flow, reduction of fans speed by 25%	Sep-Oct 2008	Factor 2 reduction of acoustic and seismic noise below ≈ 40 Hz.
10	Improvement works on the CB electrical systems distribution (work not directly for environmental noise mitigation)	Jun-Oct 2008	Electromagnetic noise gains to be measured
11	Mitigation of electromagnetic noise due to inductance loops in the fluorescent lighting of the CB mechanical lab	Jul 2008	Noise detected and eliminated by re-cabling of the circuits.
12	Electromagnetic noise coming from the MC HVAC resistive heating	Jul 2008	Noise detected. The cure needs the installation of alternative system.
13	Electromagnetic noise coming from the fluorescent lighting of the EE Room	Feb2009	Noise detected and eliminated by substitution of the equipments.
14	Improvements on separating walls in the end technical buildings	TBD	It would be useful to perform before VSR2.
15	Separation of the LL HVAC system from the CR's one		Reduced intervention scheduled on Apr 2009.
16	Installation of dampers for electric motors and fans of the CB HVAC machine		Scheduled on Apr 2009.
17	Modification works of the cold water pipeline to eliminate CB pump 1	TBD	It would be useful to perform before VSR2.
18	Reduction of the NEB HVAC machine air flow	TBD	Unlikely to perform, due to the improvements already achieved at NE with mirror change.
19	Reduction of the WEB HVAC machine air flow	TBD	It would be useful to perform before VSR2.

5 Possible solutions for the infrastructure upgrades

The infrastructure upgrades have been framed in [3] considering two options, named "*reference solution"* and "*further upgrades"*. The difference between these two scenarios concerned only the End Buildings. Even though this framework remains valid, in this document we detail the interventions considered more effective for each experimental building, trying to establish a priority scale among the foreseen interventions.

5.1 High-priority interventions

The following list states the most important infrastructures upgrades to be realized for each experimental building. Even though each group of interventions could be considered as high-priority

importance, a priority scale has been established anyway, listing the works in a decreasing grade of relevance.

A. The optimization of the HVAC equipments, both for the acoustic and the seismic performances, through:
   - the realization of independent platforms for the machines to mitigate noise transmission;
   - the suspension of the machines on adequate anti-vibrating supports;
   - the installation of damping joints for the water pipes;
   - the improvement of the air flow distribution by optimization of the air conditioning machines (air fans balancing, installation of lower noise machines) and by the replacement of the air ducts with ones of better phono-absorbing characteristics;
   - the seismic isolation of the air ducts from the walls by proper supports and from the HVAC machines by flexible joints;
   - the improvement of the air ducts noise inducing parts (curves, links, etc.) and the installation of proper air ducts silencers;
   - the upgrade of the IMMS (Infrastructure Machine Monitoring System) with the installation of new sensors and probes for the machines.

A further important evaluation about the need of replacement of the HVAC machines has to be done also taking into account the obsolescence of the current machines. In fact these machines will come to 15÷20 years 24/24h running time at the expected period of the AdV operation, no longer guaranteeing an acceptable operation in terms of efficiency and reliability.

B. The displacement of the electronics racks (or other noisy equipments like vacuum pumps) in ad hoc spaces (Electronics Equipments Room - EE Room; Vacuum pumps Room). Such action implies the realization of dedicated acoustic enclosures or the improvement of the acoustic isolation of the existing structures. These spaces are necessary, even though they may be reduced, in case the electronics racks are kept in the current positions and their cooling systems are modified (e.g. adopting conductive cooling of the electronic boards). In such case the enclosures can be used to accommodate only the power supplies and the AC/DC converters. Such actions will be effective also for the mitigation of the electromagnetic noise coming from these sources.

C. The displacement of the electromagnetic noise sources as far as possible from the towers, if such noisy equipments cannot be displaced in the suitable EE Rooms.

As general consideration, it has to be noted that the proposed displacement of the electronics depends on choices/strategies to be done by other subsystems/Virgo groups. Therefore, the exact impact of the relevant infrastructure works will be fixed after such choices have been made.
For instance, the displacement of the electronics racks currently placed on the towers platform is in contrast with the standard option for the suspension electronics. In fact the current standard is to place any possible electronics needed for the suspension control as close as possible to the tower, in order to reduce the cabling to the controls and DAQ racks.
Moreover also vacuum control electronics have important constraints to maintain their current position with respect to the towers, thus its displacements is currently under discussion.

The preliminary project of the above mentioned interventions is reported in the following (as the reference solution), with a brief description for each building and the relevant drawings.

Reference solution

Central Building - It is foreseen the realization of a new external technical area of about 150 m^2, on the east side of the Central Building (CB), to install the air handler machines (for the CB hall, the Clean Rooms and the EE Rooms) and the relevant equipments (manifolds, water pumps). The foundation supporting the machines will be ground isolated by an appropriate damping system or a

sand layer, while the machines will be set on damping pads. New water pipelines to link the machines to the Technical Building will be realized (Fig.1÷5). Other improvements concern the realization of a separate HVAC system for the Laser Lab, not connected with that of the Clean Rooms as it is at present. Finally it has been considered the realization of an EE Room hosting the electronics racks (suspensions and vacuum) and a vacuum pumps Room. The new EE Room (Fig.2) can be realized in two unused offices (CB - level 2). For this scope we need to improve the acoustic isolation of the concrete-floors and the walls. The vacuum pump Room could be realized in the hollow close to the L-Lab. (Fig.3). However, alternative locations can be evaluated.

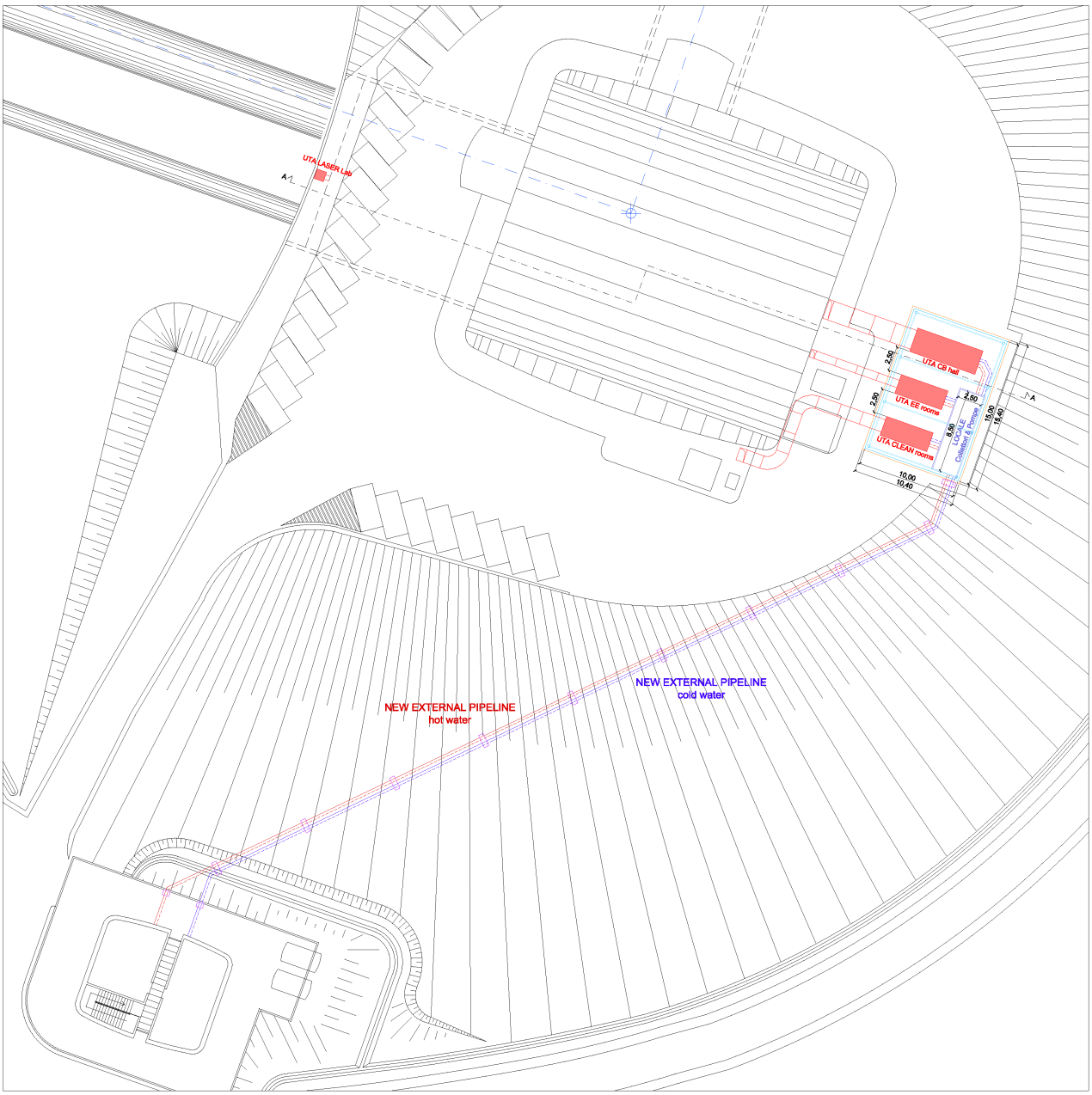


Fig. 1 – Layout of the Central Area with the new CB external technical area

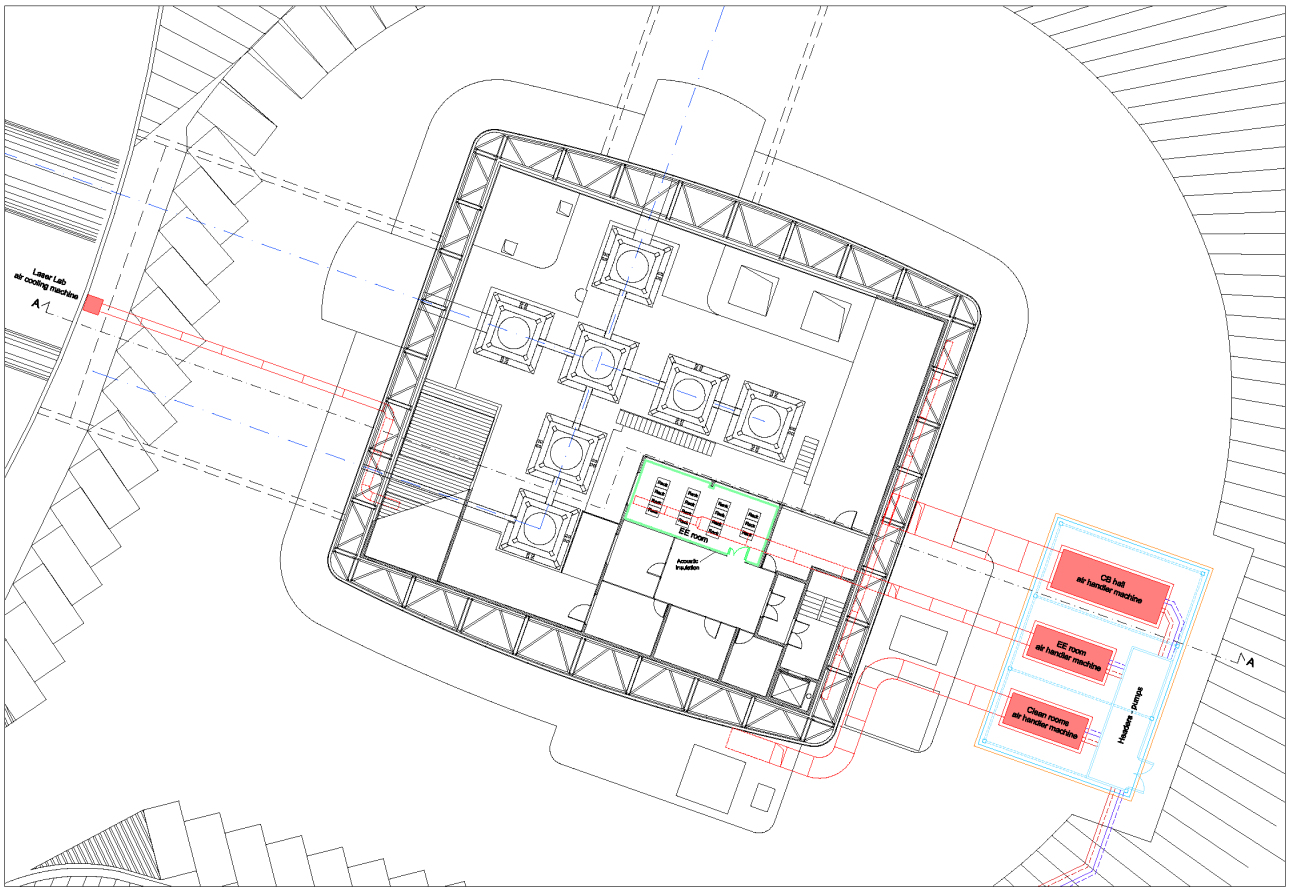


Fig. 2 – Plan view of the CB – Level 2

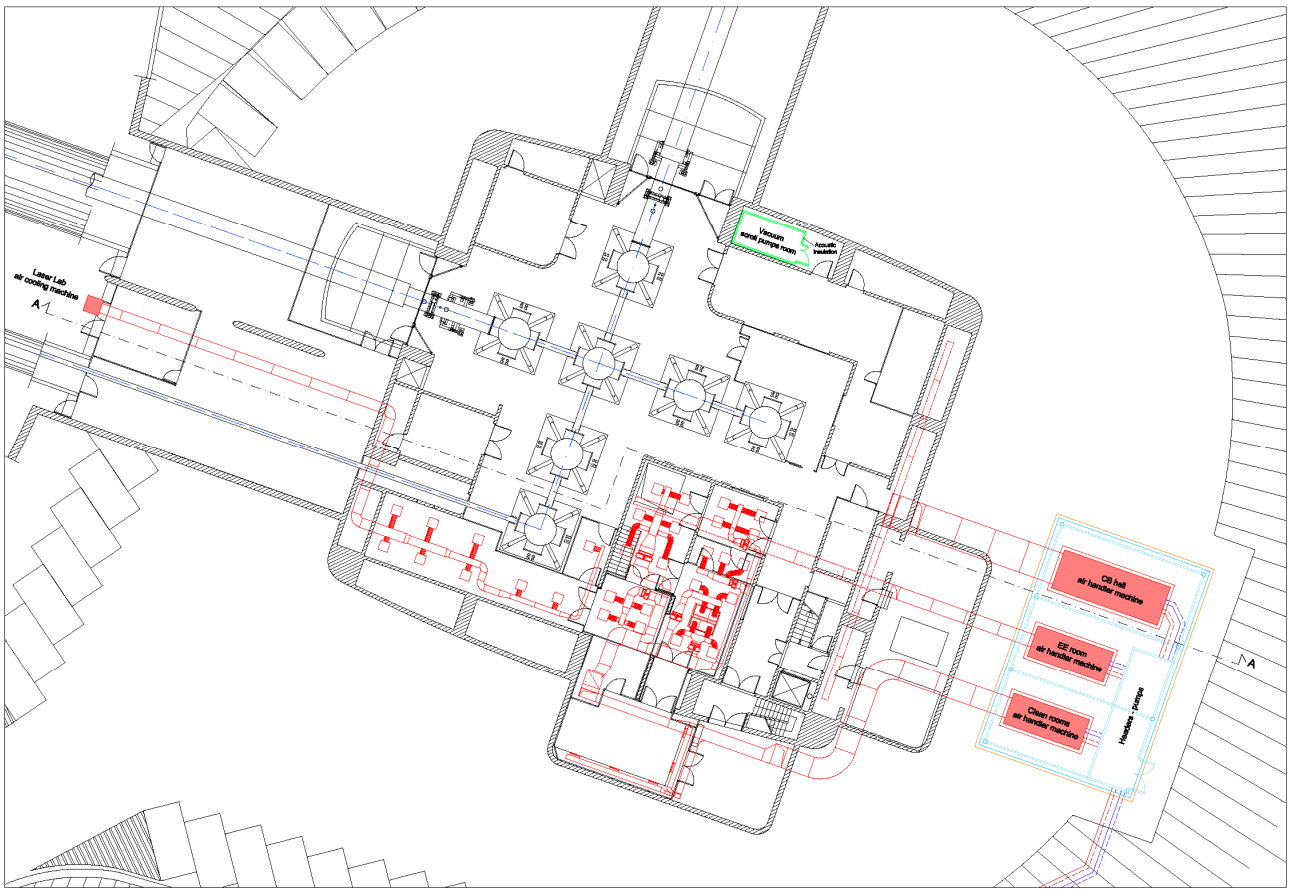


Fig. 3 – Plan view of the CB – Level 0

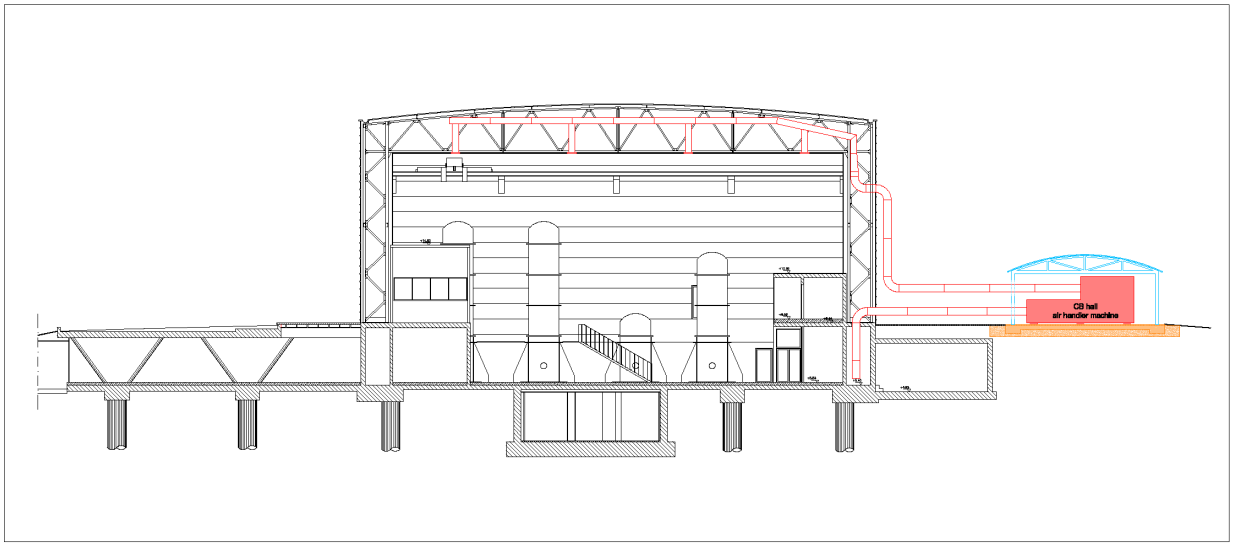


Fig. 4 – Cross section of the CB

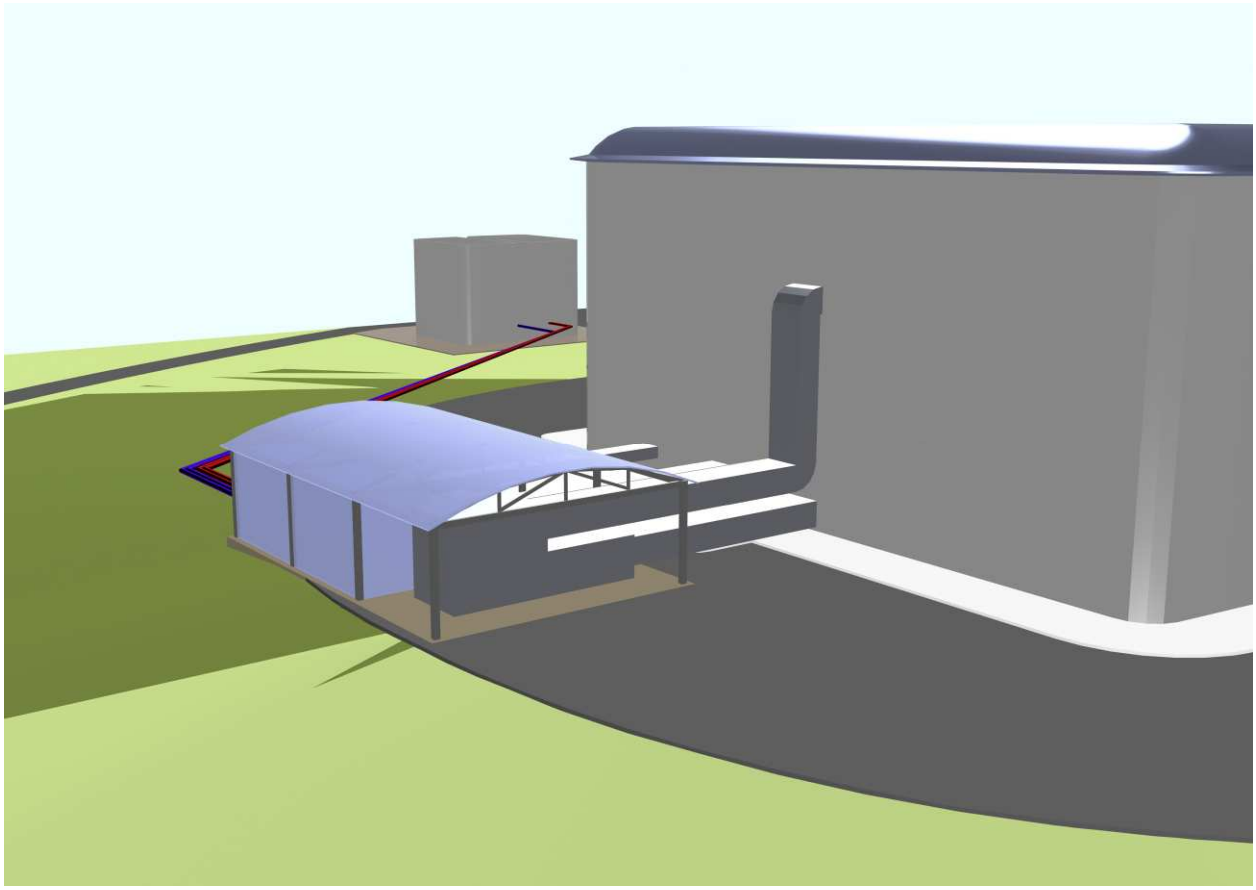


Fig. 5 – Perspective view of the Central Area with the new CB external technical area

Mode Cleaner Building - For this building we have considered the realization of an external technical area of about 25 m^2, on the west side of the building, with the same characteristics of the CB (Fig. 6, 7), to install the HVAC equipments (chillers, pumps, tanks and air handler machine). Moreover it has been foreseen the realization of an appropriate acoustic enclosure hosting the electronics racks (suspensions and vacuum). For the electronics the same recovery actions proposed for the CB can be applied.

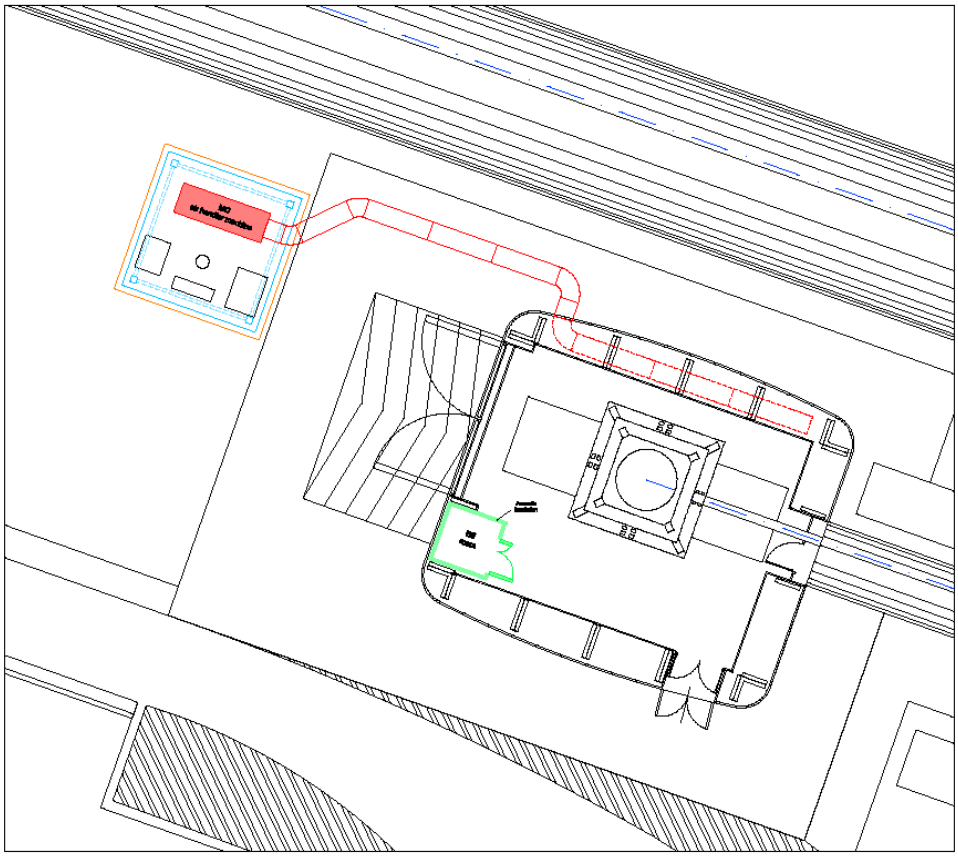


Fig. 6 – Plan view of the MC

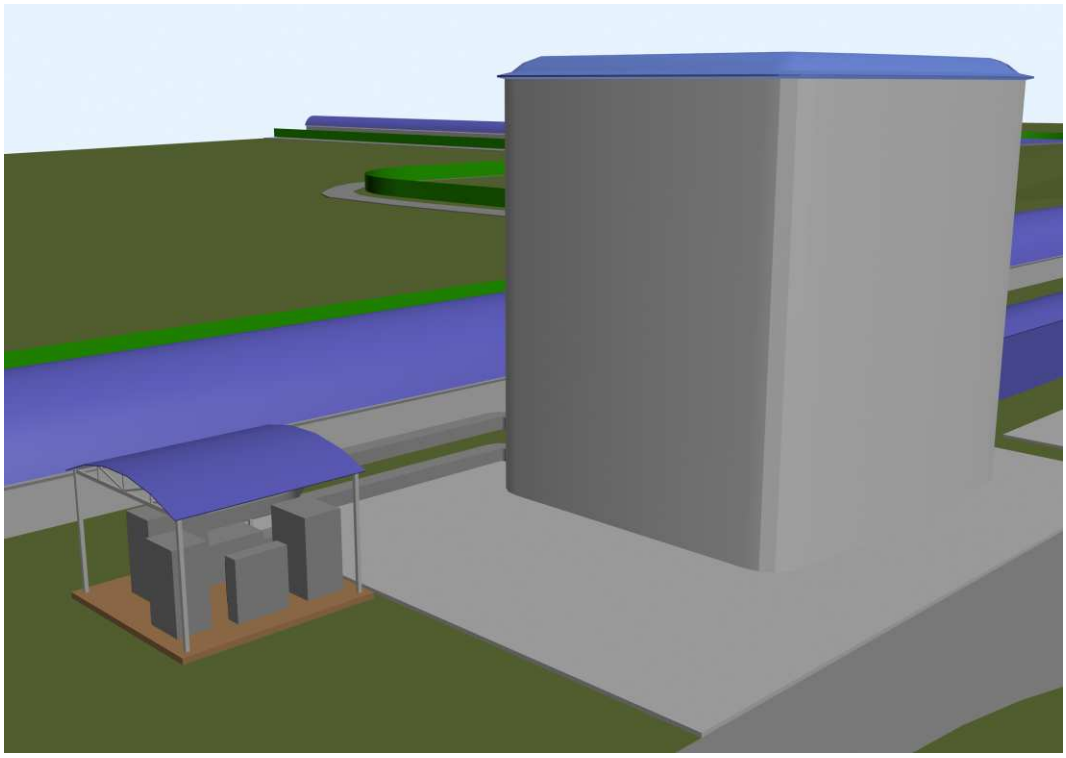


Fig. 7 – Perspective view of the MC

End Buildings - In this case the air handler machine might be kept in the current position (Fig.8, 9). In fact the floor of the technical building and the foundation of the tower are already independent by structural separations. Anyway, we have considered the realization of further structural separation between the foundation supporting the machine and the remaining part of the room. The machine will be set on damping pads and, if needed, the foundation might be rebuilt and ground isolated by a specific damping system or a sand layer. All the other machines (the heat generator, the air compressor and the electric machines) will remain in their current position, considering that as a safety distance. Even for these buildings the realization of an acoustic enclosure hosting the electronics racks (suspensions and vacuum) has been considered (location in Fig.8 is indicative to be better defined).

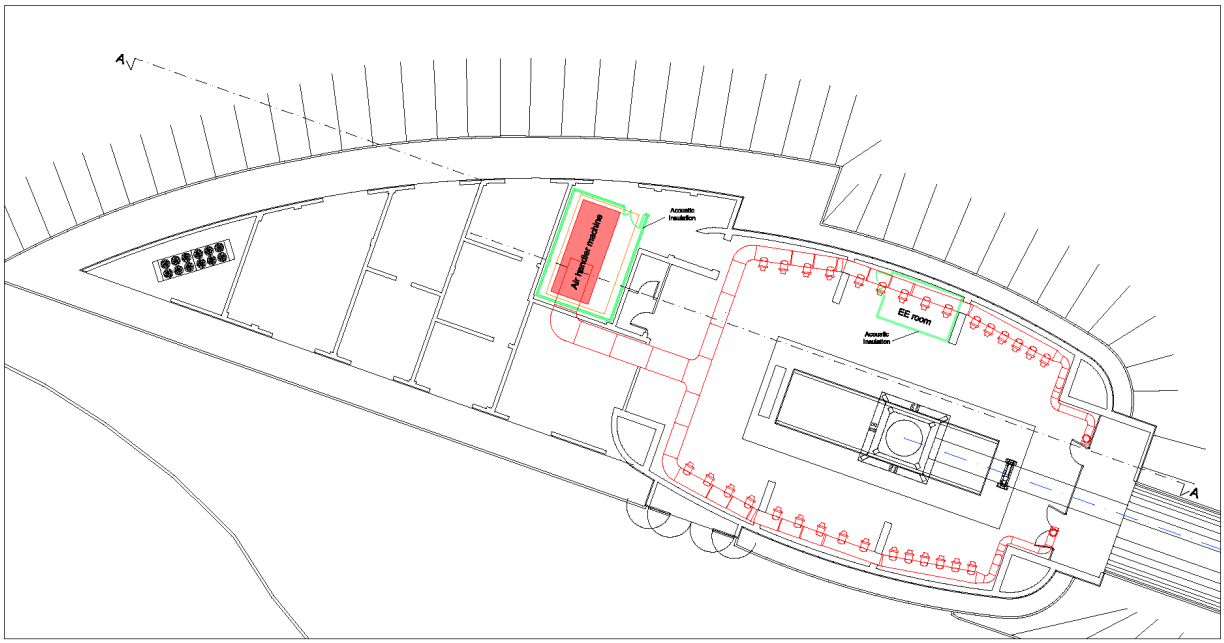


Fig. 8 – Plan view of the WEB

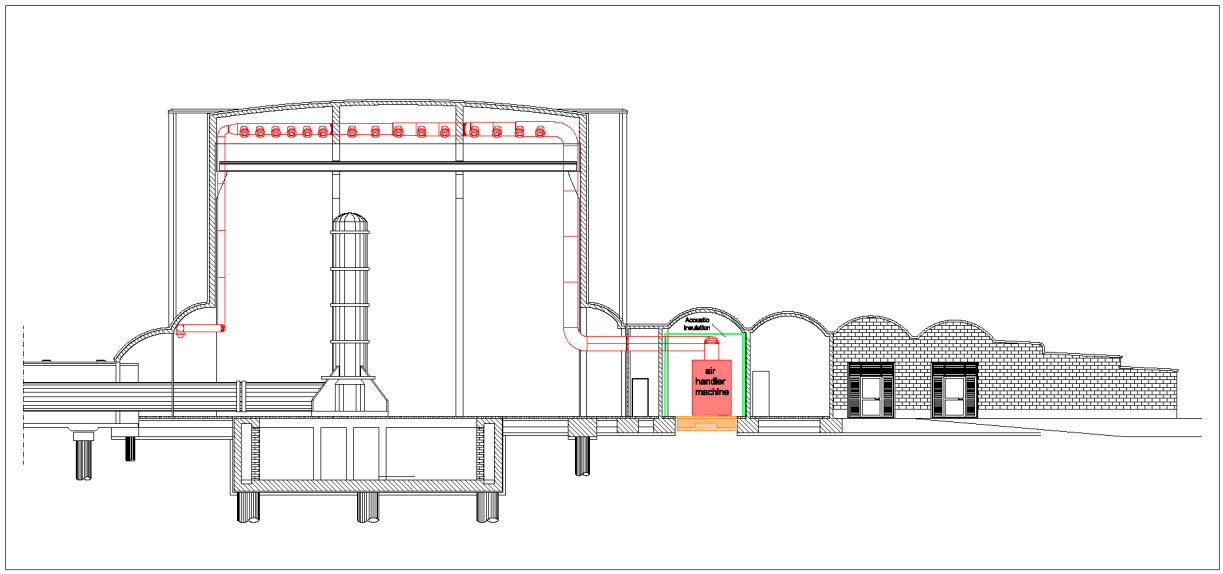


Fig. 9 – Cross section of the WEB

5.2 Other possible interventions

Other possible infrastructure mitigation works could concern the installation of proper phono-absorbing elements in the ceiling and/or the walls of each experimental hall in order to reduce the high value of their reverberation time. However the need of such works has to be carefully evaluated given their large impact and the possible side effects, such as the worsening of the cleaning conditions of the experimental halls. Nevertheless, we have to observe that these possible interventions might become of high-priority in case of other interventions unfeasibility (like electronics/vacuum pumps displacement) in order to reduce as much as possible the background level of acoustic energy in the halls.
For this reason such works have been considered in the "Reference solution", even though in the following cost evaluation tables (see par. 6) are reported only very rough estimations of possible mitigation works, based on simple solutions, given that more precise evaluations need further investigations and the development of appropriate simulating analyses.

A further grade of intervention for the environmental noise mitigation in the EBs could be envisaged by realizing a new separated technical area for the HVAC machine also for such experimental buildings, as already described in the reference solution for CB and MC. These facilities will have the same technical solutions and characteristics. The estimated surface could be of about 40-50 m^2 (Fig. 10, 11). The cost of this option has been evaluated in the "Alternative solution 2" described in the following par. 6.

Finally, it has been considered the hypothesis of realizing new technical buildings serving the EBs, in order to accommodate both the HVAC machines and the relevant equipments (tanks, water pumps) as well as the other potential noisy machines (the heat generator, the air compressor, the electric power generator, the transformer and the UPS machine), given that such machines are currently located at a lower distance from the tower with respect to the corresponding ones in the Central Area.
In this case, the estimated surface could be of about 150 m^2. However various intermediate solutions are possible, such as displacing only part of the machines in the new area and moving the remaining in the existing technical building.
Anyway, at present, such scenario seems unlikely, since first measurements showed the displacement of the electric power machines not necessary (the installed electric powers are smaller than the corresponding equipments of the Central Area), while the improvements of the HVAC mitigation works foreseen with the previous solution could be sufficient.

6 Costs

The following tables (Tab.1, 2 and 3) show a rough cost evaluation since a more precise evaluation requires detailed designs and the performance of accurate modeling analyses. Anyway, such evaluation has been performed considering the grade of development of the preliminary drawings showed in the previous paragraphs and the buildings' construction experience acquired in the past.
Tab.1 concerns the reference solution containing all the high-priority interventions, listed above with different scale of relevance (A, B and C) and the installation of phono-absorbing elements in the experimental halls, with the considerations mentioned in the previous par. 5.2.
Tab. 2 represents a possible solution differing from the previous for the HVAC machines relocation works in CB (HVAC machines remain in existing technical rooms, with improvement of the acoustic isolation performances of the structures), while Tab. 3 shows the solution considering also the moving of the EBs HVAC machines in external technical areas, likewise the other experimental buildings.
A more detailed description of the cost evaluation is reported in the corresponding Excel file available in AdV wiki – IME.

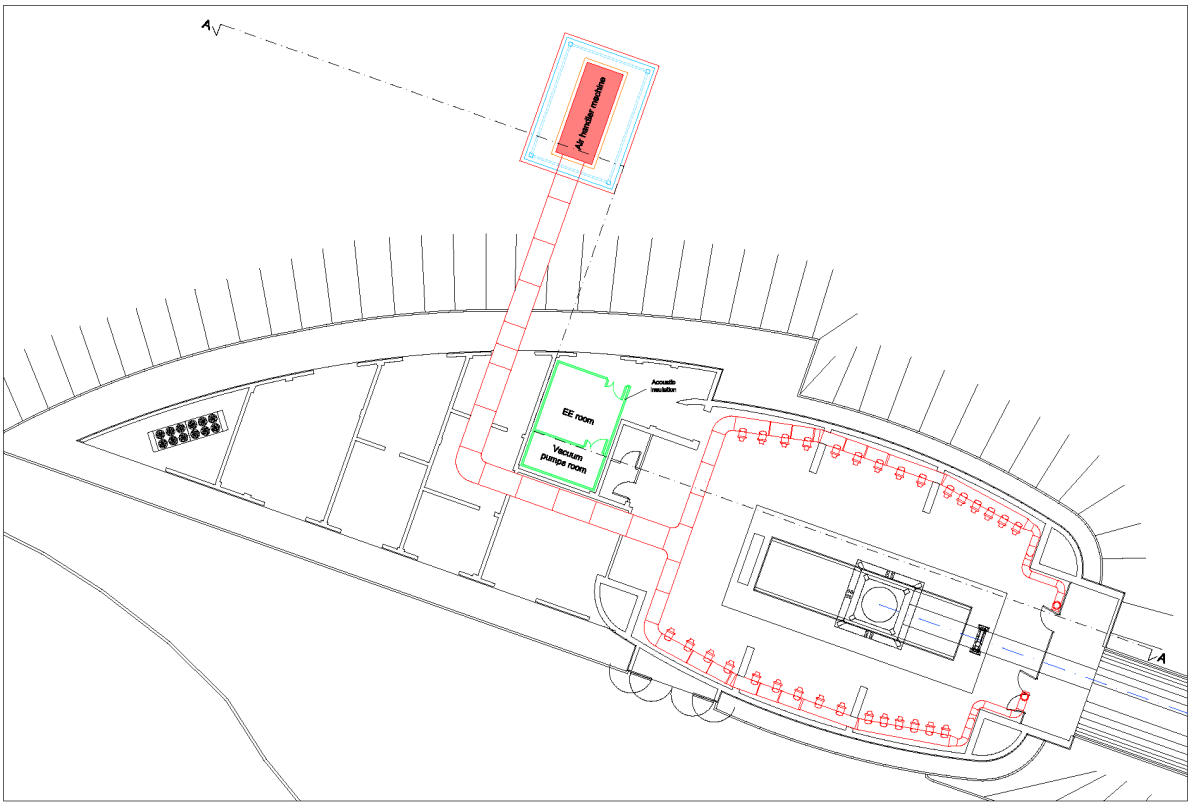


Fig. 10 – Plan view of the WEB (Alternative solution 2)

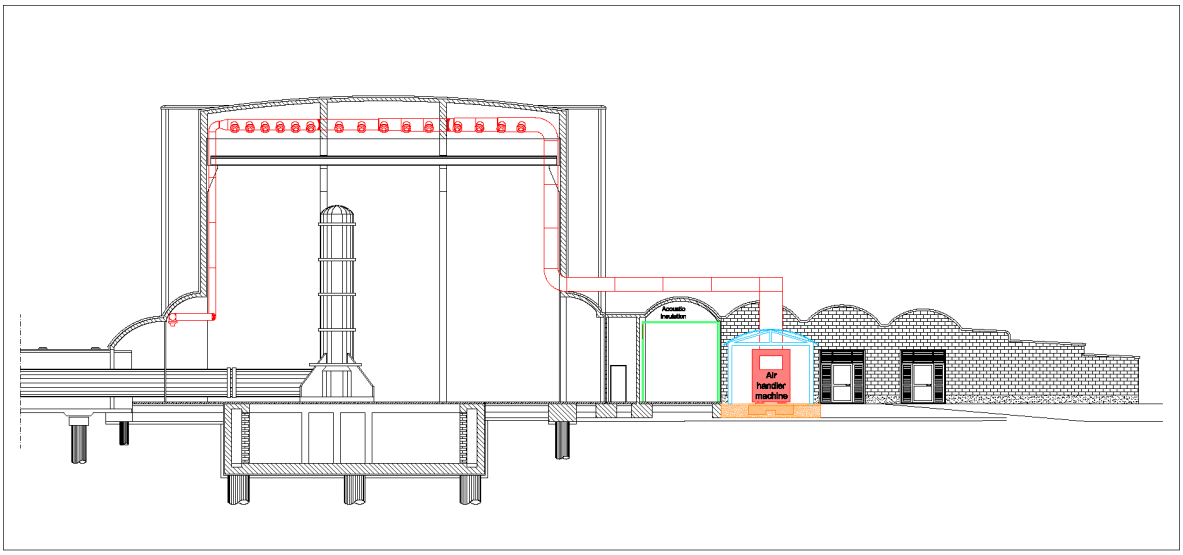


Fig. 11 – Cross section of the WEB (Alternative solution 2)

Cost evaluation summary

	Reference solution		
nr.	**item**	**categories of works included**	**cost** [k€]
1	**HVAC machines relocation**		
1.1	**Central Building**	realization of a new external technical area for the installation of the HVAC machines and the relevant equipments; realization of independent HVAC system for the LL	**429.74**
1.2	**Mode Cleaner**	realization of a new external technical area for the installation of the HVAC machines and the relevant equipments	**65.94**
1.3	**North End Building**	acoustic/seismic insulation improvement works and re-installation of the HVAC machine	**55.08**
1.4	**West End Building**	acoustic/seismic insulation improvement works and re-installation of the HVAC machine	**55.08**
	total cost HVAC machines relocation		**605.84**
2	**IMMS implementation**		
2.1	**Central Building**	electronics installation, software development	**6.00**
2.2	**Mode Cleaner**	electronics installation, software development	**3.00**
2.3	**North End Building**	electronics installation, software development	**3.00**
2.4	**West End Building**	electronics installation, software development	**3.00**
	total cost IMMS implementation		**15.00**
3	**HVAC air distribution**		
3.1	**Central Building**	air ducts installation	**120.58**
3.2	**Mode Cleaner**	air ducts installation	**13.96**
3.3	**North End Building**	air ducts installation	**30.80**
3.4	**West End Building**	air ducts installation	**30.80**
	total cost HVAC air distribution		**196.14**
4	**Electronics/vacuum pumps relocation**		
4.1	**Central Building**	EE Room, vacuum pumps Room, electric installation	**74.83**
4.2	**Mode Cleaner**	EE Room, vacuum pumps Room, electric installation, cooling system	**20.57**
4.3	**North End Building**	EE Room, vacuum pumps Room, electric installation, cooling system	**32.76**
4.4	**West End Building**	EE Room, vacuum pumps Room, electric installation, cooling system	**32.76**
	total cost electronics/vacuum pump relocation		**160.93**
5	**Halls acoustic damping**		
5.1	**Central Building**	installation of phono-absorbing materials	**72.00**
5.2	**Mode Cleaner**	installation of phono-absorbing materials	**13.50**
5.3	**North End Building**	installation of phono-absorbing materials	**48.00**
5.4	**West End Building**	installation of phono-absorbing materials	**48.00**
	total cost halls acoustic damping		**181.50**
6	**Support works to other Subsystems**		
6.1	**Central Building**	civil works, modifications of electric installations	**85.00**
6.2	**Mode Cleaner**	civil works, modifications of electric installations	**8.00**
6.3	**North End Building**	civil works, modifications of electric installations	**34.00**
6.4	**West End Building**	civil works, modifications of electric installations	**34.00**
	total cost support works to other SSs		**161.00**
	IME total cost (taxes excluded)		**1320.41**

Tab.1 – Reference solution cost evaluation

As “Alternative solution 1” we considered for the CB the re-installation of the HVAC machines in their current position after the realization of acoustic/seismic improvements works of the structures of the technical rooms. The following Tab.2 shows only the items implying cost variations, while all the other unchanged items have been omitted, and the total cost.

	Alternative solution 1			
nr.	**item**	**categories of works included**	**cost** [k€]	**var.** [%] (*)
1	**HVAC machines relocation**			
1.1	**Central Building**	realization of acoustic/seismic improvements works of the structures of the technical rooms and re-installation of the HVAC machines; realization of independent HVAC system for the LL	**390.15**	**-9.21%**
	total cost HVAC machines relocation		**566.25**	**-6.53%**
3	**HVAC air distribution**			
3.1	**Central Building**	air ducts installation	**108.58**	**-9.95%**
	total cost HVAC air distribution		**184.14**	**-6.12%**
	IME total cost (taxes excluded)		**1268.82**	**-3.91%**

(*) variation with respect to the reference solution

Tab. 2 – Alternative solution 1 cost evaluation

Finally the following Tab.3 reports the cost evaluation summary of the above considered option “Alternative solution 2”, with the same considerations made in the previous Tab.2.

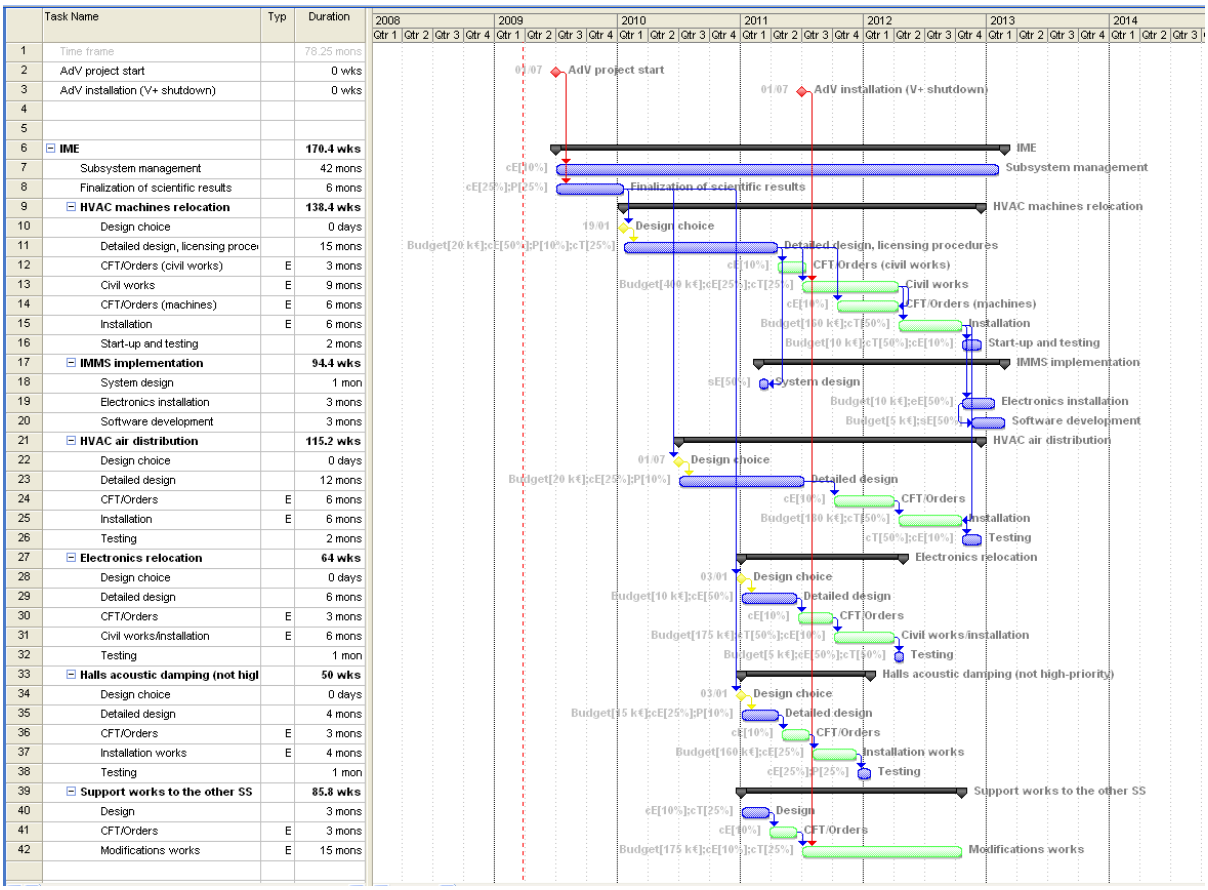
	Alternative solution 2			
nr.	**item**	**categories of works included**	**cost** [k€]	**var.** [%] (*)
1	**HVAC machines relocation**			
1.3	**North End Building**	realization of a new external technical area for the installation of the HVAC machines and the relevant equipments	**84.84**	**+54.04%**
1.4	**West End Building**	realization of a new external technical area for the installation of the HVAC machines and the relevant equipments	**84.84**	**+54.04%**
	total cost HVAC machines relocation		**665.37**	**+9.83%**
3	**HVAC air distribution**			
3.3	**North End Building**	air ducts installation	**39.80**	**+29.22%**
3.4	**West End Building**	air ducts installation	**39.80**	**+29.22%**
	total cost HVAC air distribution		**214.14**	**+9.18%**
	IME total cost (taxes excluded)		**1397.93**	**+5.87%**

(*) variation with respect to the reference solution

Tab. 3 – Alternative solution 2 cost evaluation

On the base of these preliminary evaluations we can note that the displacement of the machines out of the buildings compared with their repositioning in the current location does not imply a relevant difference of costs (about 4% more for CB, about 6% more for both the EBs with respect the total cost of the project). In fact, the increase of cost for the new civil works is balanced by higher costs for the transformation of the existing facilities and especially for the acoustically insulation works of the structures of the existing technical rooms.
Besides the works needed in case of relocation of the HVAC machines outside of the buildings are certainly easier to perform and their effectiveness easier to be checked (especially with regard to the effective result of the acoustic insulation of the existing technical rooms).
Moreover, such solution has other advantages as, during the installation period, a shorter shut down of the equipments (in particular for the Clean Rooms) and a certain simplification of future maintenance works.
In view of the aforesaid observations, the described reference solution has considered the displacement of the machines for the CB (whose requirements are higher) and MC, while keeping such option for the EBs as an alternative.

7 Planning

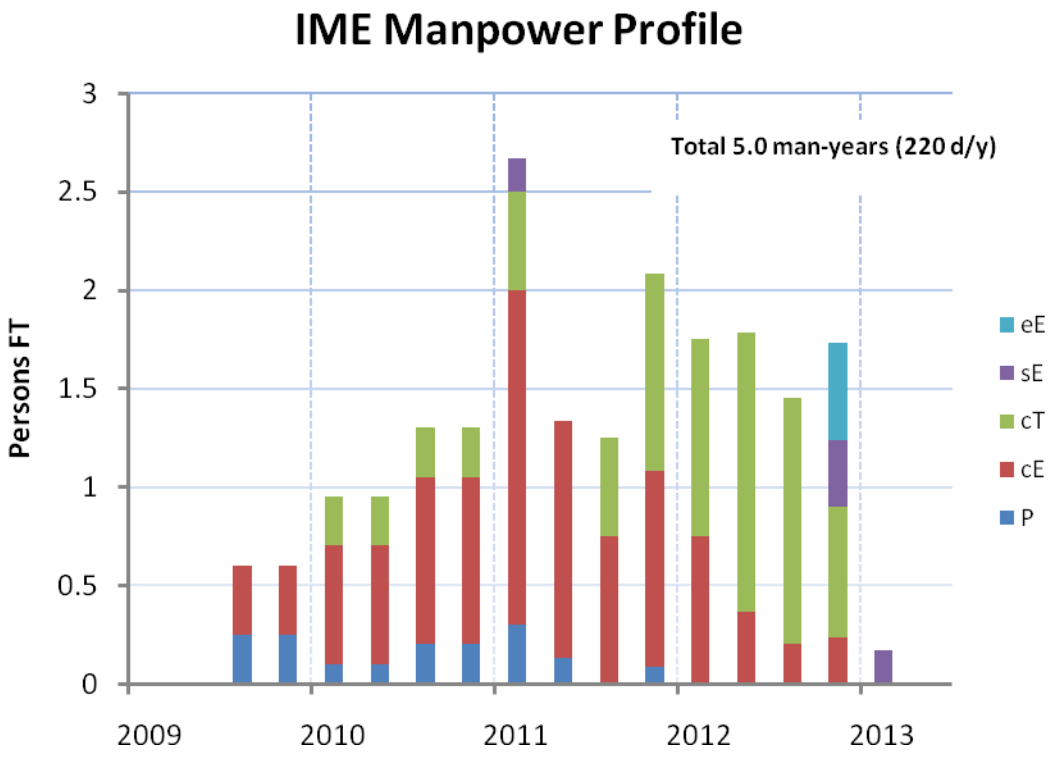


	Task Name	Typ	Duration
1	Time frame		78.25 mons
2	AdV project start		0 wks
3	AdV installation (V+ shutdown)		0 wks
4			
5			
6	**IME**		**170.4 wks**
7	Subsystem management		42 mons
8	Finalization of scientific results		6 mons
9	**HVAC machines relocation**		**138.4 wks**
10	Design choice		0 days
11	Detailed design, licensing proce		15 mons
12	CFT/Orders (civil works)	E	3 mons
13	Civil works	E	9 mons
14	CFT/Orders (machines)	E	6 mons
15	Installation	E	6 mons
16	Start-up and testing		2 mons
17	**IMMS implementation**		**94.4 wks**
18	System design		1 mon
19	Electronics installation		3 mons
20	Software development		3 mons
21	**HVAC air distribution**		**115.2 wks**
22	Design choice		0 days
23	Detailed design		12 mons
24	CFT/Orders	E	6 mons
25	Installation	E	6 mons
26	Testing		2 mons
27	**Electronics relocation**		**64 wks**
28	Design choice		0 days
29	Detailed design		6 mons
30	CFT/Orders	E	3 mons
31	Civil works/installation	E	6 mons
32	Testing		1 mon
33	**Halls acoustic damping (not higl**		**50 wks**
34	Design choice		0 days
35	Detailed design		4 mons
36	CFT/Orders	E	3 mons
37	Installation works	E	4 mons
38	Testing		1 mon
39	**Support works to the other SS**		**85.8 wks**
40	Design		3 mons
41	CFT/Orders	E	3 mons
42	Modifications works	E	15 mons

The original MS project file is available in AdV wiki – IME.

8 Manpower

The following diagram reports the foreseen manpower distribution profile during the design, installation and testing phases of the project.



References

[1] I.Fiori, “Environmental noises during Virgo and Virgo+ commissioning”.

[2] I.Fiori, “Infrastructure works for mitigation of environmental noises during Virgo and Virgo+ commissioning”.

[3] VIR-089A-08, “Advanced Virgo Preliminary Design”.