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TECHNICAL NOTES

Research laboratories: architecture and equipment between security and flexibility

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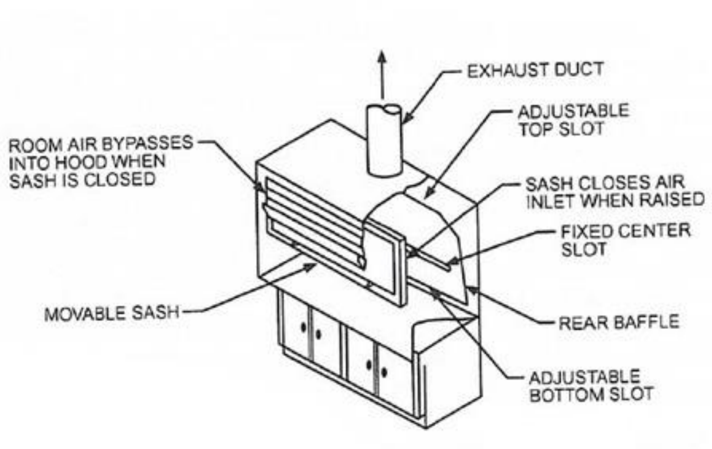
Research and experimental laboratories are the engine of scientific and technological development. The areas of scientific research are varied and often take the form of appropriate laboratories, each with special needs and facilities. The focus here is limited to chemical and biotechnological laboratories, which, because of their number, both in research institutions and in hospitals, and because of their complexity, often pose challenging design and construction problems.

In recent years, the variety of operations and consequently of the instrumental endowments and equipmentneeded in laboratories has grown enormously. This results in inevitable reflections on architectural (distributional and constructive) and plant design choices, with particular reference to the safety aspects;in this context, moreover, the need for flexibility for possible reconfigurations of activities and spaces should not be underestimated as far as possible.

Handling and operations that may give rise to the development of pollutants are carried out in laboratories inside exhaust hoods, the characteristics of which are the subject of specific standards, in particular the UNI EN 14175-X series. These hoods are certainly the element which, in the laboratories in question, poses the greatest problems both for the purely plant engineering aspects and for the safety and layout implications. As far as the plant engineering aspects are concerned, the entity and variability of the air flow rate extracted by the hoods require a corresponding prompt response from the ventilation and air-conditioning system, which is always all-air with variable flow devices, possibly integrated by hydronic terminals to cope with concentrated thermal loads due to specific equipment.

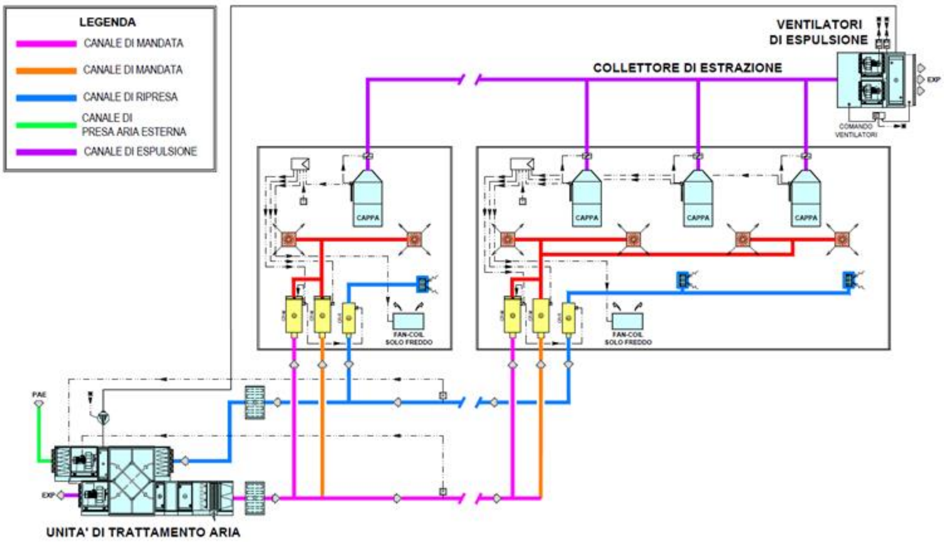


Schematic representation of a chemical laboratory exhaust hood (ASHRAE Handbook, Applications, 2023).

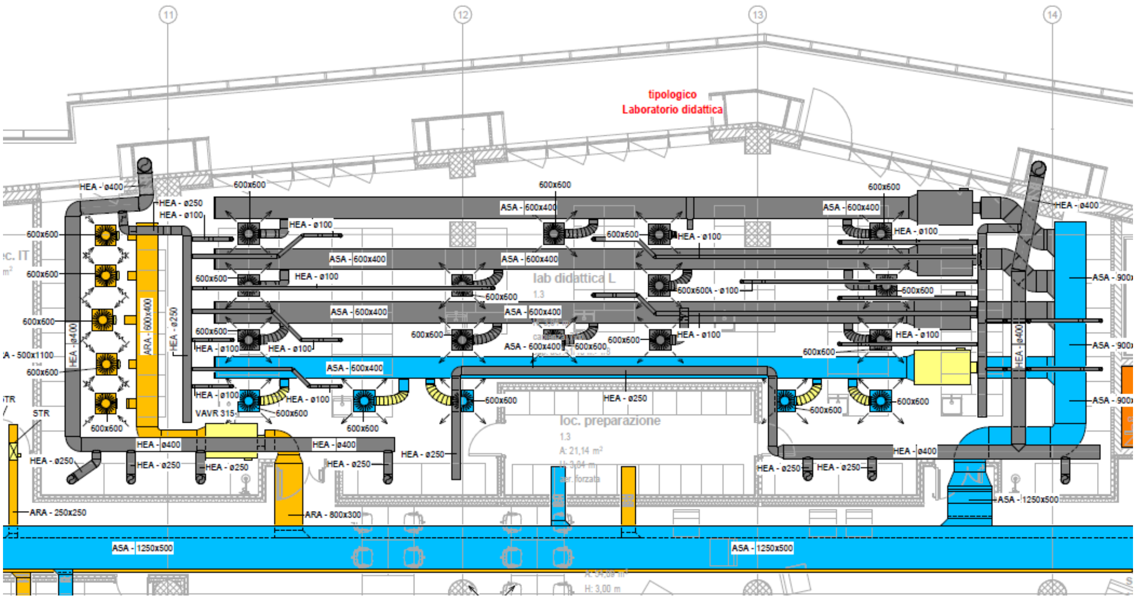
The most common exhaust hoods are 1.20 m wide and extract a maximum flow rate in the order of 1000 m^3/h to guarantee effective containment of the pollutants developed inside them. Usually, in larger laboratories, several hoods may be located in each room and the air flow rates involved become considerable and variable over time in relation to the number of active hoods and their mode of use; this situation requires very careful study of the air diffusion terminals, with possible recourse to simulations by means of computational fluid-dynamic models (CFD).

A further reason for the demand for an in-depth fluid-dynamic study of the air supply system to the laboratory derives from the need to avoid, in all operating situations, the presence of excessive velocities at the hood opening sections, as this would otherwise nullify the capability to contain the pollutants developed inside the hood itself.

A much debated question is whether it is advisable to keep the extraction ducts with their fans (generally located on the roof of the building) separate or to collect them into one or more manifolds with the respective extraction systems. In reality, the centralised system allows for greater dilution of the extracted pollutants in the air; special cases, such as the use of perchloric acid or other particularly aggressive substances, are usually resolved with specific dedicated hoods, with individual extraction. In addition, the centralised system has considerable other advantages: reduced duct development, significantly fewer fans (with consequently major ease of redundancy where necessary), the possibility of heat recovery from the exhausted air, as it is localised in a single or few positions with high flow rates, greater safety for maintenance personnel on the building roof, as the extracted air can be more easily expelled into the atmosphere in an elevated position and at high speed, instead of being spread over a large surface occupied by numerous small fans.



Typical laboratory aeraulic scheme with a centralised extraction system that maintains a constant negative pressure in the extraction manifold. Each room is equipped with three flow rate controllers to keep this pressure constant with respect to adjacent rooms: two for basic supply and return air and one to compensate for the time-varying air flow rate extracted from the hoods

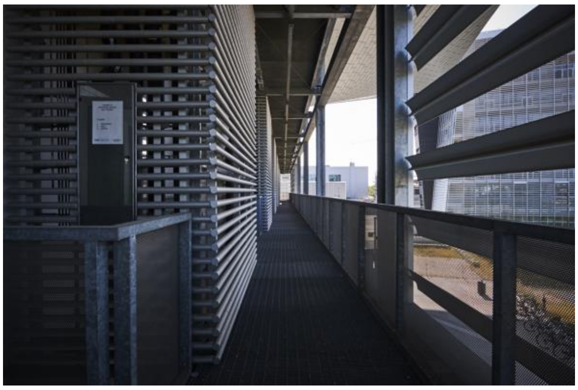


Plan of a laboratory with centralised extraction and external shafts (the duct exit on the shafts is protected by intumescent fire collars, as the walkway is an escape route). In grey, the supply of make-up air, with three flow rate controllers; in orange and light blue, respectively, the supply and basic extraction with their respective flow rate controllers (Departments of Chemistry and Pharmaceutical Sciences, University of Pavia)

Finally, the flow rate of the individual hoods is simply adjusted by means of a remote-controlled damper, with the speed control of the centralised fan maintaining the necessary negative pressure. The centralised system also offers a very simple solution for extracting air from so-called ventilated cabinets, containing hazardous substances, which are kept under negative pressure with respect to the environment to avoid harmful pollutants: the air flow, usually very small but continuous, can be easily conveyed to the collector ducts.

The pathways of the ducts of the air extracted from the hoods require special attention in order to reduce the risks of fire. They are generally made of plastic material (PVC), and their penetration through partition walls (typically technical shafts) must be protected with firebreaker devices (intumescent collars or wrap-around, or, for larger diameters, fire dampers).

Some of these aspects and other important precautions are covered in the recent standard document UNI CEN/TS 17441:2020 *'Laboratory equipment - Ventilation systems in laboratories'*.

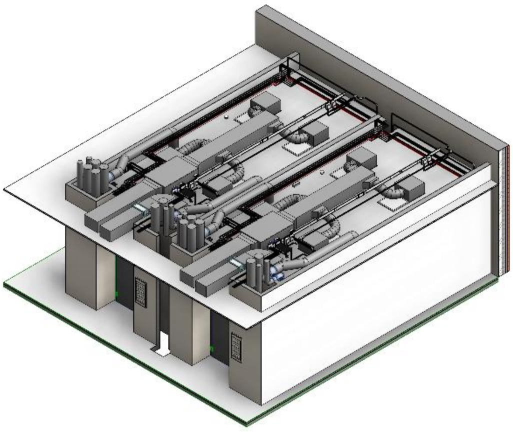
Example of a laboratory building with emergency exits on an external walkway and external shafts for housing ducts and pipes (Beta Building, Ca' Foscari University, Venice).

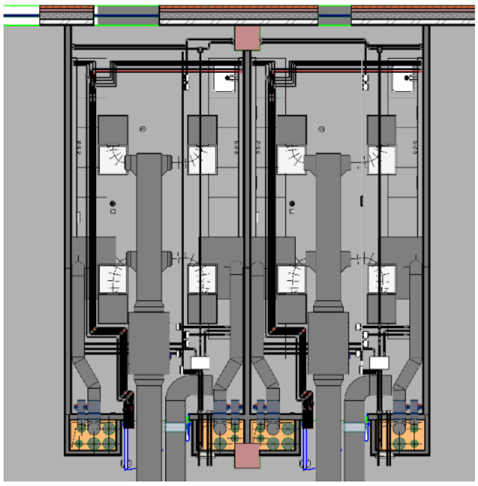
Left: general view of the façade.

Right: detail of a walkway with a grid shaft.

As already mentioned, flexibility and reconfigurability of spaces must be the guiding criteria in defining the functional organisation of these buildings. With regard to the first aspect, the design, as far as possible, must provide for the location of the various laboratories preferably on the upper floors and with an external view, both to limit the impact of plant engineering installations (especially with regard to ducts and external shafts for hoods), and to facilitate the insertion of new equipment and technologies that need to be installed externally, in which case it will be easier to connect to the roofing levels.
In this way, it is also possible to create escape routes directly from individual laboratories to external escape walkways and structures that can also be useful for anchoring technical gas distribution networks and any related items.
In the case of ducts placed externally on the façade, in addition to the undeniable advantages described above, particular consideration must be given to the possible loss of acoustic insulation due to the holes, sometimes numerous, for the passage of expulsion ducts: in order to overcome this drawback and for a harmonious integration of these elements on the façade, one can resort to closed and impervious external claddings which also solve the acoustic problem but can pose problems in terms of fire prevention as they connect fire compartments of different floors and therefore require the application of the aforementioned fireproof devices or adequate ventilation openings according to the indications of the competent authorities.
On the other hand, with regard to the theme of reconfigurability, understood as the possibility of easy functional redefinition of spaces and uses (e.g. among laboratories with different purposes or activities), it is appropriate to adopt design solutions that allow only the terminal components of the systems to be modified, leaving the primary vertical and horizontal distribution unchanged. To this end, a modular architectural and plant-engineering approach facilitates subsequent displacements of partitions in order to aggregate the available spaces in a different way according to changing needs.

If the expulsion ducts are to be located outside the building, it is also advisable to include in the design phase the provision of passage openings, for possible future ducts, to be closed off with easily removable infill elements. The masking shafts must also be easily removable and adequately dimensioned.



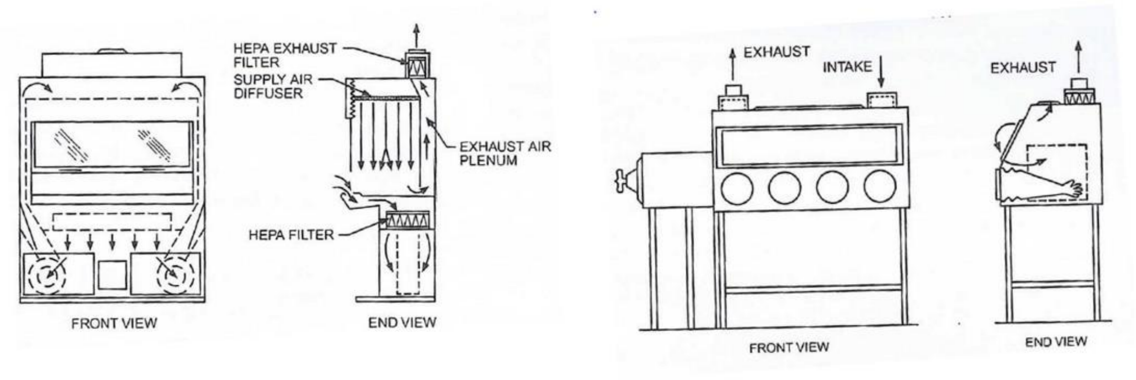


Example of an easily reconfigurable modular laboratory: the type and location of air flow controllers and other plant elements is repetitive and allows for easy modification of the dimensions of individual laboratories.

The housing shafts for the expulsion ducts in this case are inside the building for architectural reasons and the duct passages through the walls are protected, in the event of fire, by intumescent collars. (Mind Complex, University of Milan, Rho (MI)

Left: axonometric view
Right: floor plan

A particular category is that of biotechnology laboratories, where substances with the presence of micro-organisms are handled that can be classified according to their level of risk to humans and the environment: this establishes the level of safety (BSL: Biological Safety Level) of the relevant laboratories classified from BSL-1 to BSL-4 according to standard UNI EN 12741 *'Biotechnology - Laboratories for research, development and analysis - Guide for operations in biotechnology laboratories'*. A fortiori, even in these laboratories dangerous manipulations are carried out within special containment hoods, which are also classified according to the level of protection they must ensure towards the sample under examination, the operator and the environment. The highest level of safety involves the use of class III hoods where the working area is totally enclosed and the operator is separated from it by a physical barrier (glove box). The air, which is almost completely recirculated inside the hood, is all filtered and then continuously introduced into the operating volume, which is in any case maintained in negative pressure by the extraction of a quantity of air that is also HEPA filtered, sometimes in two stages, and rejected back into the same environment or channelled outwards.



Schematic representation of two types of containment hood for biotechnology laboratories.

On the left is a class II exhaust hood: the absolute filtered air curtain (HEPA), with downward laminar flow, protects the object being handled and a unidirectional flow entering the hood, maintained in depression by a HEPA-filtered extraction, protects the operator.

On the right a class III hood: the working area is totally insulated and kept under negative pressure, with respect to the environment, and the operator carries out the manipulation through glove-shaped, perfectly sealed penetrations

(ASHRAE Handbook, Applications, 2023).

In addition to what has been described above, laboratories require other equipment and services, and fundamental among these is the supply of various so-called 'technical' gases: nitrogen, oxygen and methane, are the most common, but argon, helium, hydrogen, carbon dioxide, silane and others are also used, sometimes with a high degree of purity. Storage facilities and pipeline networks are used for distribution to individual laboratories. There are many possible solutions: a trend that is spreading in the case of large complexes, such as university departments and research institutes, is to keep the storage and distribution of certain gases, such as nitrogen and oxygen, centralised, especially when they come from the regasification of cryogenic liquids, while splitting the supply of other gases to groups of laboratories, possibly belonging to the same research section, into several separate plants, with smaller storage tanks made up of cylinders. In this case deposits can be located on the roof of buildings or at the base of external shafts, if present, allowing, among other things, the reduction of the path between cylinder and user, a particularly useful expedient for high purity gases, whose characteristics can be altered by excessive pipe lengths, however carefully installed and maintained.

Special equipment is also often required, such as safety cabinets under negative pressure for storing hazardous substances or (also burst-proof) for containing small cylinders of particular gases.

Example of a suction arm for local removal of pollutants from out-of-hood processing (Airum Technical Doc.)

In many other aspects, impossible to cover here, HVAC and electrical systems in laboratories are involved, such as fire prevention and safety systems, redundancy of ventilation or air-conditioning equipment, continuity of power supply for essential functions (generator and uninterruptible power supply units), safety lighting, access control, environmental sterilisation with ultraviolet lamps (to be used when rooms are unoccupied), access with airlocks, filters with interlocked doors, contained drains for hazardous liquids with the possibility of analysis and treatment, installation of decontamination showers, emergency washbasins and eye fountains, localised suction arms, and more.

These notes reveal the global complexity of the design of a building intended to house a research laboratory: even more than in other cases, the concept of integrated design of the building-plant system proves to be important. The constraints presented are considerable: functionality, safety, comfort and flexibility of use, but it should not be forgotten that a place of this nature must also be welcoming and representative of the hosted institution.

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