19. DUCTING SYSTEMS – LOCATION, DESIGN, INSPECTION AND CLEANING

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This chapter discusses the importance of designing and installing efficient ducting systems, how they are integrated into buildings, quality requirements, and how function and operating costs are dependent on having an airtight system.

WHY IS IT IMPORTANT TO HAVE AN EFFICIENT DUCTING SYSTEM?

When two or more rooms are connected to a common ventilation system, a ducting system will be required to supply, distribute and remove the air. There are, however, a number of reasons why the system, from a functional point of view, might be unsatisfactory, with problems caused by:

- Air leaking into or out of the ducts because they are poorly sealed.
- High air speeds giving rise to disturbing noise levels.
- Dust and other pollutants in the ducts resulting in health problems.

It is important that duct systems are designed with due care – they will normally be used for a great number of years and will have a significant effect on the amount of energy used by the ventilation system. The total amount of energy used by a ventilation system is often equally divided between the ducting system and air handling plant.

Another important aspect is the role played by the ducts in transmitting, creating and damping noise in a building. Ducts passing through adjacent rooms can transmit sound and impair the sound reduction properties between them.

Careful planning and common sense are always required when aiming for acceptable results. In most cases, ductwork will form an integral part of a ventilation system, installed with the purpose of providing an accept-

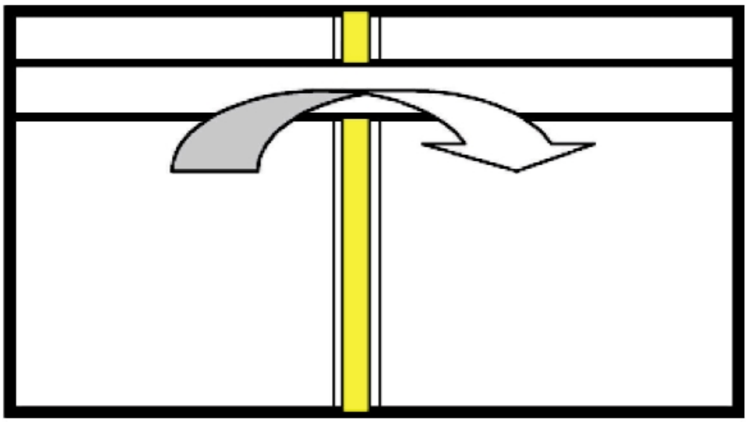

FIGURE 1. Crosstalk – noise transmitted between two rooms via a ventilation duct.

able climate and good air quality. However, it does not follow that any noise created by the system is acceptable: a great many people experience a true feeling of relief when the ventilation system is switched off at the end of the day and silence returns. Dissatisfaction caused by noisy ventilation systems must be avoided and it is important to pay as much attention to the acoustic design of a system as to other air quality and thermal climate factors that affect well-being and comfort.

Silence – or the absence of noise – is now often a rare commodity and too little can lead to stress and discomfort. And remember, prevention is better than cure – problem-solving at a later stage will be more difficult and expensive, and require more time and effort to provide satisfactory solutions. It is also harder to convince people who have been discontented that they should now be satisfied.

More about this topic can be found in Chapter 26/Sound and sound attenuation, in which the creation and damping of noise in ductwork is also discussed.

DUCTS AND COMPONENTS

Development and stricter requirements

Manufacturing methods for ventilation ducts and components during recent decades have progressed from manual and time-consuming work, relying on the professional skills of sheet-metal workers, to large-scale industrial production and the assembly of complete systems by fitters on site. At the same time, the system of using tailor-made ducts and components, made to measure on site, gave way to industrially manufactured and stocked ducts, with standardized dimensions and component design, for example of bends and junctions.

A great and important step in this development work was taken when machines were introduced in the 1960s to manufacture cylindrical, spiral-seam ducts in standard sizes. Previously, circular ducts had hardly been used at all.

Demands for airtight ducts were made at the beginning of the 1970s and they resulted in the development of rectangular ducts that were fitted with different types of rubber seals at the joints, replacing putty and tape that had been used before. The circular ducts were also later fitted with rubber seals that were pressed into place when the duct sections were joined together, see Figure 2.

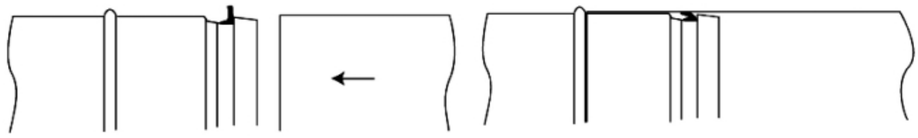

FIGURE 2. Joining circular duct sections fitted with rubber seals.

To prevent the joints from sliding apart they are then fixed in position using pop rivets or special screws. One manufacturer has recently introduced a solution whereby the joints are firmly held together without rivets or screws, which greatly facilitates the installation work.

Greater demands on airtightness were followed by demands to carry out checks when the ventilation system was put into operation. As better design solutions were produced, the demands on airtightness increased, see the section on requirements, tests and inspection below.

Types of ducts

A ducting system normally comprises a combination of rectangular ducts, installed closest to the supply air handling equipment where the air flow is the greatest, and circular ducts further downstream in the system, where the air is distributed to the different parts of the building and the different rooms.

Duct sections are normally made of galvanized sheet steel. In corrosive environments, occurring inside or outside the ductwork, stainless steel, aluminium and sheet-steel coated in an alloy of aluminium and zinc are also used. Even synthetic materials (PVC, polyamide, etc) can be used, for example, for extract air ducts in laboratories.

As mentioned above, duct cross-sections can be circular and rectangular. In some countries, flat-oval ducts are used as well. These are made by either pressing together or drawing apart circular ducts.

Rectangular ducts

Rectangular ducts are manufactured in heights and widths according to the EN 1505 dimensioning standard, in steps of 100 mm up to 600 mm and thereafter in steps of 200 mm. This means that there are a great number of possible combinations for straight duct sections and even more for components and specially formed fittings, such as bends and junctions, which means that it is impossible for suppliers to keep them all in stock. The length of the duct sections is normally limited to 2.4 m, which corresponds to the standard length of the galvanized sheets used in their manufacture.

The sections are normally joined using slide-on cleats, which press the flanges of the duct sections, and the rubber seal in between them, together. The larger the ducts, the stronger the cleat required, see Figure 3. The four corners of the rectangular duct sections are often fitted with bolt holes to ensure that the sections are kept in a straight line and at the same time facilitate the assembly of the cleats. Sufficient space must always be left around the flanges for the cleats and assembly tools.

Pressure variations in the ductwork can cause the flat sides of the ducts to vibrate and this could cause disturbing noise. To prevent this, the sides are normally stiffened by cross-creasing, see Figure 4, by transverse stiffening, see Figure 5, or by attaching exterior ribbing.

Struts inside ductwork should be avoided, as they can cause noise and make cleaning more difficult.

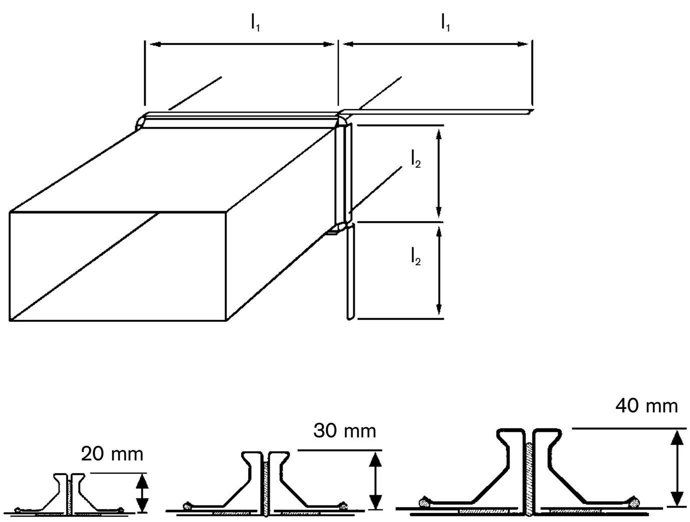

FIGURE 3. The larger the duct, the larger the flanges required. Extra space is also needed so that the cleats can be attached.

FIGURE 4. Cross-creased duct.

FIGURE 5. Transverse-stiffened duct.

Circular ducts
All circular metal ducts manufactured today are made from rolls of galvanized steel sheet, aluminium or stainless steel that are fed into a spiral folding machine. There are a number of different machine manufacturers although all the machines, in principle, are quite similar and are based on the original design concept. The metal strip is rolled into a standard-diameter duct with standardized allowable tolerances with regard to finished dimensions.

Unlike the rectangular ducts, the circular ducts are made in fewer sizes. The standardized dimensions are based on a mathematical series in which successive diameters increase in the ratio of $1{:}\sqrt[3]{2}$ (i.e. by about 27%). Note that the one-third octave bands used in building acoustics, see Chapter 11/Building acoustics, follow the same mathematical series.

The following duct diameters are commonly used in Europe:
63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250 and 1600 mm.
Other diameters, used in other countries, include:
355, 450, 560, 710, 900, 1120 and 1400 mm.

The length of the circular duct sections is only limited by transport regulations – the machine can continue to produce a duct until the strip runs out or the workshop becomes too small! Duct sections are normally cut into 3 m lengths, though lengths up to 6 m have been produced, transported and installed. If long duct sections can be used, fewer joints will be required and this will reduce installation time and leakage risks. In one special case, when a large number of large-diameter (1600 mm) duct sections were needed, the spiral folding machine was moved to the building site to avoid transportation problems.

Components for circular ducting, for example, bends, can be turned in any direction, which means there is only need for one type of bend for each duct dimension, as opposed to the numerous types required for rectangular or flat-oval ducts.

Flat-oval ducts

One disadvantage of circular ducts is that they cannot be made flatter when narrow spaces have to be negotiated. This is where the use of rectangular ducts can be advantageous, even if a number of parallel circular ducts, instead of a single low and wide rectangular duct, can be used, see the sub-section *Planning space carefully* below.

A compromise that is used in a number of countries is the flat-oval duct, mentioned above. The sections are manufactured as circular lengths and then pressed together or drawn apart using special tools to give them their flat-oval shape. They are used instead of rectangular ducts in places where heights are limited. These ducts should only be used where there is an over-pressure in the duct, i.e. in supply air ducts, otherwise there is a risk of them becoming even flatter than intended. On the other hand, the over-pressure must not be so great that it causes the duct to revert to its original round shape.

One of the disadvantages of flat-oval ducts, compared to circular ducts, is that joining the duct sections and components, as well as the design of the components, is much more complicated. Additionally, as in the case of rectangular ducts, there are so many possible combinations of heights and widths that prefabrication and the carrying of stocks becomes impossible.

Strength

Duct systems must be able to meet requirements regarding:

- Mechanical strength
- Corrosion resistance
- Vibration fatigue

The ductwork must also be installed using fixings that are strong enough to withstand the loads that the system might be subject to. Many of these requirements are specified in European standards. Ducts are subject either to an over-pressure (supply air) or an under-pressure (extract air) and must be able to meet specific requirements in these respects, depending on their size.

The dimensions for rectangular ducts and components are stipulated in EN 1505 and the requirements for airtightness and mechanical strength in EN 1507.

The dimensions for circular ducts and components are stipulated in EN 1506 and the requirements for airtightness and mechanical strength in EN 12237.

The importance of correct corrosion protection
To ensure that the ducts will have an acceptably long operational life, it is essential that the correct material qualities be chosen, with respect to the environments in which they will be used. If the ducts are to be installed in corrosive environments, the standard quality – galvanized sheet steel – is not durable enough. Either extra treatment, by applying a sufficiently thick coat of paint of suitable quality, or a more corrosion-resistant material is required, see the sub-section *Types of ducts* above.

Table 1 shows how quickly a zinc layer can corrode in different environments. A common problem that arises in climate systems is caused by condensation dripping from a cold surface onto galvanized steel ductwork. This must be prevented by providing the cold surface with sufficient thermal insulation and a vapour barrier or by moving the condensation source away from the ducting. The reason why the rate of corrosion is so rapid is that condensation, like distilled water, does not contain salts.

TABLE 1. Corrosion rates for zinc in different environments.

Environment	**Approximate rate of corrosion, µm/year**
Indoors	<0.5
Inland countryside district	<1
Coastal districts	
Towns	1 to 3
Countryside	0.5 to 2
Industrial areas	2 to 10
Sea water	
North Sea	12 to 46
Baltic	about 10
Distilled water	50 to 200
Soil	500

Example:
Standard quality ventilation ducts are made of galvanized sheet steel class Z275. The class designation means that 1 m^2 of the sheet is coated with 275 g of zinc equally applied to both sides. This provides an average thickness of 20 µm of zinc. If the duct is installed indoors in a dry environment, it will take more than 40 years before the zinc layers have corroded to such an extent that the sheet will start to rust. If, on the other hand, the duct is subject to condensation with an approximate corrosion rate of 50 to 200 µm/year, see Table 1, it will start to rust after only a few months.

The importance of correct insulation
There are three reasons why ducts might have to be insulated and three corresponding types of insulation are available:

1. *Thermal insulation,* which creates a thermal barrier between the inside and outside of the duct.
2. *Fire insulation,* which prevents fire from spreading through the wall of the duct.
3. *Acoustic insulation* placed on the inside of the duct, which absorbs sound, or placed on the outside, which increases the sound reduction index of the duct wall, and thereby prevents sound from entering or leaving the duct. See Chapter 26/Sound and sound attenuation.

Sometimes there is a simultaneous need, for example, to meet thermal insulation and fire insulation requirements. The most cost-effective solution might be to combine these two requirements and choose a type and thickness of insulation that satisfies both. The requirement that is most important varies from case to case. Normally, fire protection requirements demand thicker insulation than energy-efficiency requirements.

Common to all applications is that the insulation material must be fireproof and mineral wool or fibreglass is therefore normally used. The insulation material is usually wrapped around the outside of the duct, except when the material is used for sound absorption. The insides of intake ducts, between the intake grilles and the air handling plant, used to be lined with thermal insulation and the metal duct then acted as a vapour barrier between the cold, dry air inside the duct and the warm, humid air on the outside of the duct. The disadvantage of this solution was that the outdoor air that was drawn into the system did not pass through any sort of filter. This meant that the air often contained dust and, together with raindrops and snowflakes, created viable, but highly undesirable, breeding grounds for microbial growth in the insulation material.

If the air in the supply air equipment is cooled to a temperature under the dew point of the air in the building, it is important that the insulation, enclosed in a suitable vapour barrier, is wrapped around the outside of the duct, i.e. where the partial vapour pressure of the air is higher than that of the air next to the cold duct.

It is extremely important that the vapour barrier, for example plastic sheeting or galvanized steel, is completely airtight, otherwise water vapour will penetrate, diffuse, into the insulation material and probably corrode the wall of the duct. Insulating material that becomes wet will loose most of its insulation capacity.

If acceptable from a hygienic point of view, the insulation material can be placed inside the duct wall and the wall will then act as a vapour barrier against the surroundings. When insulation material is used to line a duct, it is important that the material chosen can be cleaned using standard methods, see the section on cleaning ventilation ducts below. It is equally important that the material cannot emit particles into the air, i.e. cannot erode, at the air speeds encountered in the duct.

Decisions about location and design must be made jointly

PLANNING THE DUCTWORK

Although the HVAC design engineer will try to avoid long and difficult routes for the ductwork, unsuitably located shafts will make it difficult to design an efficient system.

The design and location of ductwork should therefore be carried out in consultation with the architect. It is important to remember that sufficient space must be reserved for building services installations. If consultations are carried out at an early stage in the project, the results can be advantageous to both parties. This is discussed further in the sub-section *Will the installations be pleasing to the eye?* below.

One or a number of systems?

The first logical step when planning a ventilation system for a building is to decide on whether it will be served by one single supply and extract air system or a number of systems. The decision should be based on the following factors:

- The size of the building and required air flows – the greater the needs, the more advantageous it could be to divide the system into sub-systems. In a large, low-rise building the ductwork will be extensive, costly and difficult to design, if all the air has to be supplied from a single point.

- The number of users/tenants – will they have different demands regarding operating times for the ventilation system? This could be the case if the building comprises both offices and shops. Separating the systems could reduce energy usage, as it will not be necessary to run the whole system just for the sake of one of the tenants.
- Will the users/tenants have different demands regarding air quality and thermal comfort? This will most probably result in the need for different technical solutions that will be easier to manage if separate systems are installed. If the users/tenants are going to pay for their respective solutions, having separate systems will make it easier to proportion costs between them.
- The creation of fire cells and other safety considerations could make it easier and safer to design the ventilation system with individual fire cells rather than to design a single system for the whole building.

Layout and low pressure drops

The design of the ducting system greatly affects the pressure drops and, consequently, the energy needed to transport the air through the system. The required fan power is given by the following equation:

$$P = \frac{q \cdot p_{tot}}{\eta} \qquad (1)$$

where:

P is the fan power in kW

q is the air flow provided by the fan, i.e. the nominal flow plus leakage, in m^3/s

p_{tot} is the total pressure rise across the fan, i.e. the pressure drop across the plant and in the duct system, in Pa

η the total efficiency of the fan

The fan power P can therefore also be expressed as:

$$P = f(q \cdot p)$$

and, as $p = f(q)^2$, then $P = f(q)^3$ (2)

The pressure in a duct system can be regarded as the energy that has been supplied by the fan and has been converted into kinetic energy (air flow). This is then irreversibly reduced due to friction against the duct walls or turbulence, for example, at bends or sudden duct enlargements. These losses, normally termed pressure drops or flow resistance, must be overcome by the fan so that the design air flows can be supplied via the supply air terminal devices in the system.

Pressure drops cost money, as they are directly connected to the energy used by the fan. It is important, therefore, that the design engineer calculates the pressure drops across plant and in the duct system and tries to reduce unnecessary losses.

The air flow in a duct is dependent on the reduction of pressure in the duct in the direction of flow. Pressure losses are caused by friction and local flow restrictions in the components.

Both types of loss are caused by local changes in speed:

- Friction corresponds to the force that is required to accelerate the air that leaves the low speed zone along the walls of the duct and moves into the high speed zone in the centre of the duct.
- Component losses correspond to the forces that are required to create local increases in average air speeds in the duct system.

To reduce the pressure losses in a system, it must be designed to be as smooth and unrestricted as possible:

- Sudden changes of cross-section and sharp bends without guide vanes should be avoided.
- The placing of duct components at a distance of less than five duct diameters from each other should be avoided.

Locations for fans and air handling plant

There are a number of pointers to be followed when deciding where to install fans and air handling equipment:

1. Avoid locations next to sound-sensitive spaces, such as conference rooms.
2. Choose locations close to the spaces that they are going to serve to minimize the length of ductwork required. This will save costs, energy and space.
3. Locate air handling equipment and supply air fans close to suitably located outdoor air intakes.

4. Fans and air handling equipment require regular service and maintenance and it must be possible to replace worn-out parts when required. Locate them to facilitate this work. Avoid locations that are difficult to access, for example, in lofts and on roofs, especially in cold climates and in high buildings. Carefully consider how maintenance work will be carried out and what will be required. Do not forget that spaces like these are working spaces for the maintenance staff and they should therefore be planned as such.

Location of outdoor air intakes and exhaust air outlets
Outdoor air intakes must be located where it can be presumed that the surrounding air is clean. It is best to locate them:
- High up on the rear side of a building away from traffic exhaust fumes.
- On the north side rather than on the sunny east, south and west sides.
- At a safe distance from exhaust air outlets – in the same or neighbouring buildings. Note prevailing wind directions, vertical and horizontal distances to other intakes and outlets.
- At a safe distance from cooling towers and evaporative condensers, to reduce the risk of legionella spreading to the building via the supply air system. *Legionella pneumophila* bacteria can be found in the small water droplets emitted, for example, from cooling towers.

The location of exhaust air outlets must not create problems in your own or any neighbouring building.

Location of duct shafts
Study the different floors in the building and how the supply air and extract air flows are to be distributed. Try to choose shafts that are located as centrally as possible. The more symmetrically the ducts can join up at the shafts, the lower the costs and space requirements for the ductwork.

Symmetrical branch systems in the riser ducts and in the connecting ductwork on each floor will reduce pressure drops and, consequently, the energy required to convey the air.

In large buildings that are divided up into a number of fire cells, it is often advantageous to separate the supply air and extract air ducts and locate them in separate shafts. The shafts can then be regarded as individual fire cells, provided that the shaft walls have been designed appropriately.

For structural reasons, the duct shafts are often placed next to the lift shafts. In long buildings, with a lift shaft at each end, it is often a good idea to place the supply air ducts in one of them and the extract air ducts in the other.

Note that the shafts must be accessible from every floor, both for installation work and future modifications. In large buildings, with a number of ducts in each shaft, the shafts often have their own lighting systems and are fitted with steel working platforms and inspection doors on each floor.

Symmetrical design

Symmetrical duct systems have a number of advantages and should be used wherever possible. When the design air flow for every terminal device is the same, a symmetrical layout will provide an equal pressure drop in all the terminals and installation work will also be much easier. Figure 6 shows a symmetrically designed sub-system, in which the supply air is introduced at point 1 and its flow is halved at every subsequent T-joint, until it reaches the terminal devices at the ends of the stub ducts. The air flow at each device is one eighth of the original flow at point 1.

On reaching each terminal device, the air will have passed identical duct components with identical dimensions and pressure drops. When symmetrical, branched sub-systems are used the commissioning work is

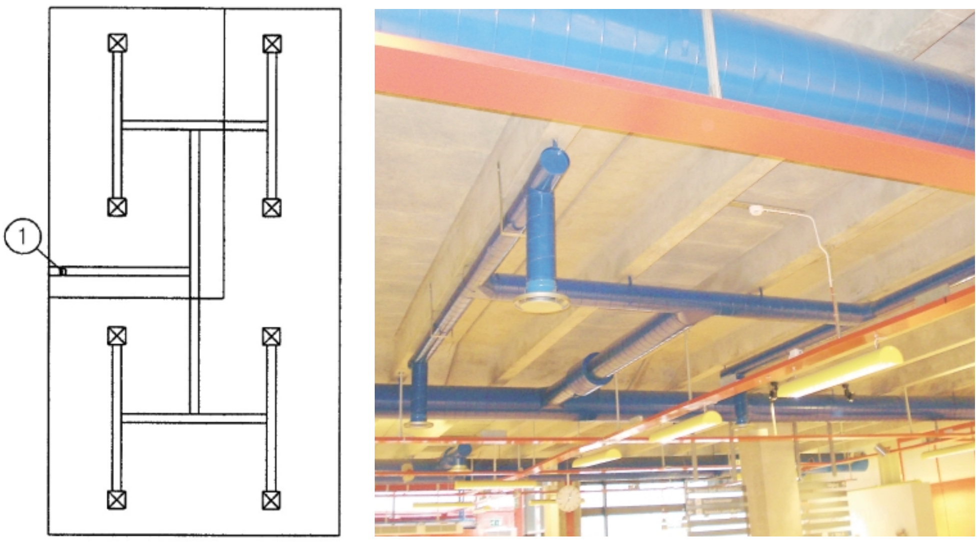

FIGURE 6. A symmetrical sub-system in which the supply air, introduced at point 1, is distributed via identical duct components on its way to the terminal devices.

simplified, as the pressure drops in the different terminal devices are the same and their dampers can be given the same setting. There will be no need for balancing dampers except, possibly, to distribute the air between different sub-systems, see Chapter 29/Balancing ventilation systems.

Designing installations to be flexible

A building is normally designed for a long operational life, often considerably longer than the operational life of the original building services installations. Demands made on the building and the building services can change over time. New tenants and changes in use of a building often mean that new demands are made on the services installations. It is therefore important to consider the demands for installation flexibility and the future uses of the building:

- Will the original installation provide reasonable margins – with regard to plant and ductwork – to be able to cope with moderate increases in air flows? Having low air flow rates in the ducts will make it possible to cope with higher loads whereas high initial levels of energy use and of noise in ducts, components and terminal devices could hinder future changes. Higher investment costs can be regarded as taking out an insurance policy, one that will pay off very generously, if and when functional changes have to be made in the system.
- Are the plant rooms, shafts, suspended ceilings etc sufficiently large to accommodate new plant and installations that will fulfil higher demands? Spaces and access routes that are too narrow will otherwise make it difficult or even prohibit future changes, which could cause the value of the property to fall. Even here, the initial investment in extra space could prove to be very profitable when future changes in building use or HVAC functions are required.

When choosing between these two alternatives – flexibility or more available space – the former should be chosen, if changes can be expected in the near future, i.e. within about ten years, and the latter if changes are first expected later on.

Special care must be taken when solutions are chosen that entail integrating the installations with the structural design of a building. This could lead to difficult and expensive rebuilding work if the ducts, for some reason, need replacing in the future. For environmental reasons, materials that are recyclable should always be used if possible and sandwich solutions, in which a number of materials are combined, should be avoided, as these prevent rational sorting when they have to be replaced at some point in the future.

Plan space carefully
As mentioned above, it is important to ensure that the installations have enough space, both for the original solution and possible future changes. Careful space planning should aim at ensuring that the plant and equipment can be:

- Easily moved within the building
- Easily installed – are shafts and other spaces sufficiently large so that joining and insulation work can be carried out correctly?
- Tested
- Commissioned
- Maintained
- Repaired
- Removed from the building when they are no longer needed

Ducts, both rectangular and circular, require a lot of space when compared to other installations such as cables and pipes. They also require space for handling and are difficult to manoeuvre, especially when there is a collision risk with other installations. To prevent collisions, a common problem when different services are installed in corridor ceilings, it is important that the project engineers and contractors carefully study potential congestion points at an early stage and deal with the questions concerning what should be installed where and in what order.

Drawing up cross-sections of difficult areas, so that everyone knows what space is available, is a practical way of tackling situations like these and will save both time and money. This might be regarded as a rather laborious task but it can pay big dividends. It will speed up the installation process and reduce the number of disagreements between the different contractors on site. It can also be referred to if one of the contractors uses space outside the agreed limits or installs pieces of equipment that make it difficult for other contractors to carry out their work. The person in the wrong will be obliged to make amends!

In the sub-section *Rectangular ducts* above, it was shown how duct sections could be joined using cleats. A relatively large amount of space is normally required for fitting the cleats onto flanges, between 20 mm and 40 mm high on every side of the two duct ends. This must be taken into consideration when choosing type of duct, dimensions and suitable shafts. An inexperienced design engineer might assume that the logical solution for ductwork in rectangular shafts is rectangular ductwork, where circular ductwork might, in fact, be easier to install.

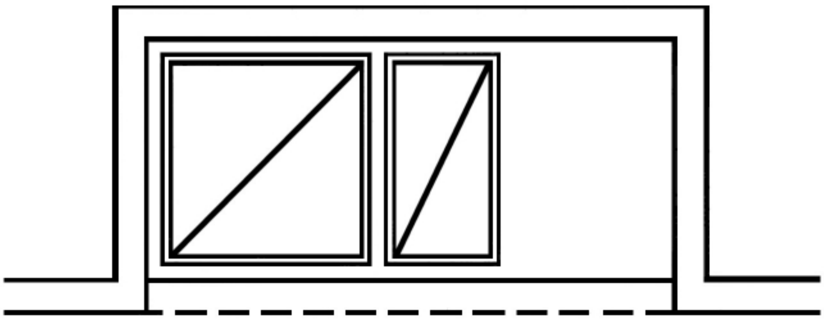

FIGURE 7. So far so good – it then becomes difficult to utilize the rest of the space in the shaft!

The space needed to assemble circular ducts is often less than for rectangular ducts designed to accommodate the same pressure drops. When ducts are installed in the ceiling of an office corridor or in a duct shaft, where the ducts, in both cases, are only accessible from one side, this often causes major problems, as the flanges on the far side are difficult to reach.

Even here, the cost of the finished ductwork might be lower if the circular alternative were used and, at the same time, this might facilitate balancing and zoning.

When the critical areas of a building are designed in detail, it is important to consider the installation methods that are going to be used. As an example, we can look at the installation of ducts to be wrapped in insulation. When the duct itself has been installed – which requires space for joining and suspension – the insulator has to start work. Free space will be needed around the duct for positioning and attaching the insulation material, and possibly a vapour barrier as well. If the ducts have been placed too close to the ceiling, walls or other installations, it will not be possible to carry out this work to the required standards.

Access routes and installation space must be designed so that workers' protection and safety are taken into consideration. Maintenance personnel often have to carry heavy tools and very large spare parts, for example, replacement filters. They must be able to carry out their work in a safe and ergonomic way. Fixed ladders are difficult to negotiate if equipment has to be carried at the same time, as both hands are needed for climbing.

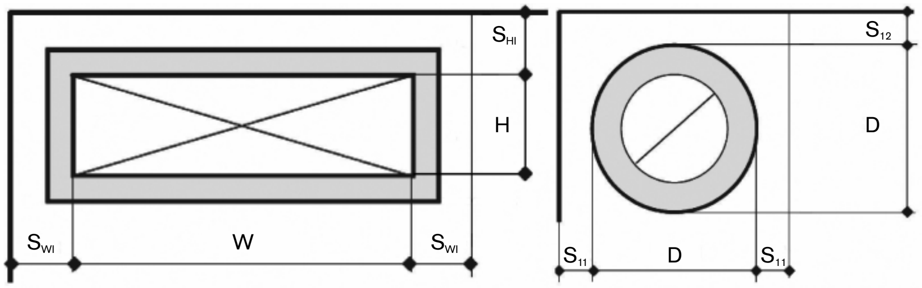

FIGURE 8. Free-space requirements for external insulation. Distances are shown in Table 3.

TABLE 2. Spaces required for 100 mm of external insulation.

Duct size, mm		**Rectangular ducts**		**Circular ducts**	
Circular D (incl. 100 mm insulation)	Rectangular W or H	S_{W1} mm	S_{H1} mm	S_{11} mm	S_{12} mm
≤ 160				≥ 100	≥ 50
$> 160 \leq 300$				≥ 200	≥ 100
$> 300 \leq 500$				≥ 300	≥ 100
$> 500 \leq 800$				≥ 400	≥ 100
> 800				≥ 500	≥ 150
	W, H ≤ 700	≥ 400	≥ 400		
	$700 <$ W, H ≤ 1200	≥ 600	≥ 400		
	W, H > 1200	≥ 600	≥ 600		

Can the duct shaft be accessed so that changes and additions can be made? Can lifting gear be used to lift heavy equipment, such as plant units and fans? Are access routes, doors and service shafts sufficiently wide and high for moving equipment etc?

Will the installations be pleasing to the eye?

A building is a system and, if it is to function as intended, the building services installations must also function properly. There is a popular trend among architects to allow installations to be part of the design of the building. This means that ductwork is not hidden above suspended ceilings or behind screens but is completely visible, forming part of the interior design.

FIGURE 9. Ventilation ducts in two of the atriums at Ramböll's Gothenburg office.

FIGURE 10. Ventilation ducts in a Stockholm restaurant.

Figures 9 and 10 above show examples from buildings where the architect has chosen to put the ventilation ducts on view. In Figure 9, the ductwork in the building's four atriums has been painted in different colours to improve orientation within the building. Even on the different floors the circular ducts are painted and on view and not hidden above suspended ceilings, as is normally the case in offices buildings. In Figure 10, it can be seen how ducts have been painted and on view, in different colours as part of the interior design. The restaurant is situated in a large office building.

This requires close cooperation between the architect and the HVAC engineer and their work must start at an early stage in the planning process if both parties are to benefit.

Figure 11 shows how different ducting systems can be colour-coded to facilitate recognition.

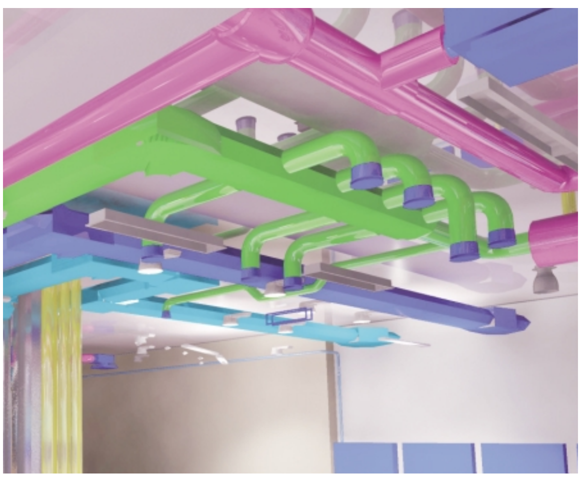

FIGURE 11. Colour-coded ducting.

If room heights are not limited by installing suspended ceilings, this could mean lower building costs. At the same time, the greater free height of the room and its larger ventilated volume will normally contribute to an improved indoor climate. This is because the extra space is created high up in the room where the concentration of pollutants is normally higher and this means that the ventilation air can be used more effectively. Having direct contact between the ventilation air and the ceiling makes it possible to use cool outdoor air to cool the building. This does not mean that suspended ceilings are not necessary, but they should be used primarily for acoustic reasons.

If installations are planned to be visible, they must be of very high standard, professionally designed and installed, and live up to expectations, otherwise they should not be chosen.

REQUIREMENTS, TESTS AND INSPECTIONS

Requirements must be expressed in verifiable terms

Requirements concerning duct systems are normally specified in tender and contract documents. The findings in EU projects [Andersson et al., 1999] and [Andersson et al., 2002] showed that differences when specifying requirements and checking them varied greatly in different countries, and this resulted in great variations in quality. For example, airtightness requirements for ventilation ducts in Sweden were considerably stricter than in two other countries that were investigated.

A probable explanation was that the Swedish AMA (General Material and Workmanship Specifications) system had been in use since 1950 and requirements concerning air handling systems had been expressed in verifiable terms. For example, requirements for airtightness in duct systems had been included in the Swedish 'HVAC' AMA since 1968. See the sub-section *Testing a duct system for airtightness* below.

Airtightness requirements for duct systems

Different studies have shown that air leakage from duct systems can result in a greatly increased use of energy. There are two reasons for this:

1. Fans have to work harder.
   The air flow through a fan is directly affected by any air leakages from the ductwork. If the design air flow is to reach the terminal devices, the fan must be dimensioned for and provide an air flow that is the sum of the nominal flow, i.e. the combined air flows to the terminal devices, and the leakage that occurs on the way to and from them.

As the power required by the fan is proportional to the cube of the air flow, Equation (2), the power requirement will increase by:

$$\Delta P = \left(\frac{q_{tot}}{q_{tot}-q_{leak}}\right)^3 \text{ kW} \qquad (3)$$

where:
q_{tot} is the total air flow through the fan in m^3/s
q_{leak} is the air leakage in the ductwork in m^3/s

This means that a 5 % air leakage will require a fan power increase of nearly 20 %.

$$\Delta P = \left(\frac{1}{1-0.05}\right)^3 \approx 1.20$$

2. Increased thermal losses.
   Treated supply air – heated or cooled – that leaks on its way to a room will also lose the energy that was used for treating it.
   If the supply air and extract air ducts are placed in the same suspended ceiling space, air that leaks out of the supply air ducts will be sucked into the extract air duct, without having first passed through any of the rooms.
   Leaking ducts are detrimental to ventilation systems as they have a negative effect on energy efficiency, thermal comfort and air quality.

Upper limits for allowable air leakage are therefore required to:
- Minimize costs and energy losses that would otherwise be a result in an over-dimensioned and inefficient plant.
- Simplify commissioning.
- Minimize noise occurring at leakage points.
- Limit infiltration from and leakage into spaces that do not require air treatment.

A duct system will never be absolutely airtight and such a requirement cannot be stipulated. Instead, limits are stipulated regarding how much air is allowed to leak at a given pressure, normalized to the duct system's total surface area.

Air leakage classes for duct systems

The following classification, which came into force in Sweden in connection with the revised 'HVAC' AMA in 1972, is also used as a basis for classifications according to Eurovent, the European air handling and refrigeration equipment manufacturer's association. The classification stipulates the maximum leakage per m² duct surface area expressed as a leakage factor K:

$$K = \frac{q_v}{A \cdot \Delta p_{ref}^{0,65}} \qquad (4)$$

where:

q_v is the leakage flow in m³/s

A is the surface area of the tested duct in m²

Δp_{ref} is the reference pressure used during testing in Pa

TABLE 3. Airtightness classes and leakage flows according to Eurovent 2/2 ('HVAC' AMA) and ASHRAE.

Airtightness class according to Eurovent 2/2 $l/(s \cdot m^2 \cdot Pa^{0.65})$	**Leakage flow at 100 Pa l/s per m²**	**Leakage flow at 400 Pa l/s per m²**	**Leakage classes acc. to ASHRAE $ml/(s \cdot m^2 \cdot Pa^{0.65})$**
Class A $(K < K_A = 0.027)$	0.54	**1.33**	27.0
Class B $(K < K_B = 0.009)$	0.18	**0.44**	9.0
Class C $(K < K_C = 0.003)$	0.06	**0.15**	3.0
Class D $(K < K_D = 0.001)$	0.02	**0.05**	1.0

Although Airtightness Class D is not defined in Eurovent 2/2, it is used in a number of European countries, including Sweden. A test pressure of 400 Pa is used in Sweden ('HVAC' AMA 98).

Testing a duct system for airtightness

The reasons for having airtight ducts have been discussed in the sub-section *Airtightness requirements for duct systems* above. This means that the client must express requirements in verifiable terms – terms which the contractor can understand, accept and price – and carry out random checks to verify the airtightness in connection with the final building inspection and when taking possession of the building.

An EU project [Andersson et al., 1999] showed that this was not often the case. When no requirements had been specified and no testing had been carried out, it could be seen that the quality of the installed

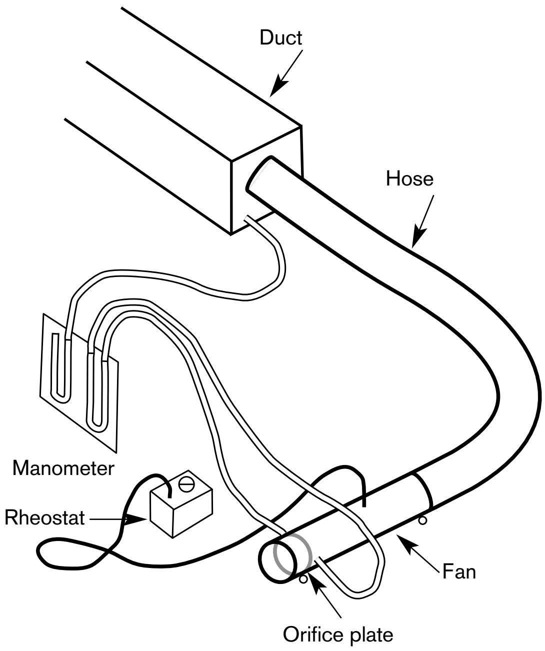

FIGURE 12. Typical measuring equipment for testing airtightness in ducts.

duct systems was very low. This is relatively self-evident – if quality is not demanded and checks not made, quality cannot be provided.

When comparing the measured leakages in duct systems in Belgium, France and Sweden, it was shown that duct systems in Sweden were, on average, 25 to 50 times more airtight than corresponding systems in the other two countries. The reason for this lies in the fact that, as pointed out earlier, airtightness in ducts has been stipulated in contract documents according to the 'HVAC' AMA since 1968, and that these demands have gradually become stricter as different technologies have developed and, in turn, given rise to even higher demands.

The airtightness classifications in the latest version of the 'HVAC' AMA, published in 1998, are as follows:

- *Airtightness class A,* the lowest requirement level, which defines requirements for visibly installed ducts in the space being served. A leakage here will not have any real significance, as any extra air flows, besides those through the supply and extract air terminal devices, will be beneficial to the space.
- *Airtightness class B* (three times tighter than A), which defines requirements for rectangular ducts and circular ducts in duct systems with surface areas ≤20 m^2.

- *Airtightness class C* (three times tighter than B), which defines requirements for circular duct systems with surface areas >20 m^2.
- *Airtightness class D* (three times tighter than C) is not a standard classification in the 'HVAC' AMA 98, but can be specified for systems in which airtightness is essential. Circular duct systems that comply with these requirements are now available.

Airtightness requirements are verified by random testing and the results are reported on special forms as part of the contractor's assignment.

The number of the random tests varies depending on type of ducts used: 10% of the circular ductwork in a contract and 20% of the rectangular ductwork are standard proportions according to the 'HVAC' AMA. The normal testing pressure is 400 Pa.

If it is shown that these tested sections meet the airtightness requirements, then the ductwork will be approved. If it is shown that a tested duct leaks more than allowed, depending on its class, it will have to be sealed and retested together with another 10% of the circular ducts and 20% of the rectangular ducts. If retesting shows that the ducts meet the requirements, then the ductwork will be approved. If it is shown that the retested ducts leak more than their classification allows, the ducts must be sealed and the tests extended to include all ducts included in the contract.

These requirements mean that it will be very expensive for contractors, if they are forced to carry out more than the nominal testing included in their contracts and that has been included in their costs. They will have to pay for all further testing – something that ought to be an incentive to make sure that work is carried out correctly from the start.

A three-country comparison of airtightness in ducts

In the EU SAVE-DUCT project [Andersson et al., 1999], carried out in Belgium, France and Sweden, the airtightness of a large number of duct systems was investigated. It was shown that the leakages in the Belgian and French systems were, on average, three times higher than those allowed in Sweden for Class A ducts. The corresponding average leakages in Sweden were between Class B and Class C, see Figure 13.

Balancing air flows

It is important that the air flows to different rooms in a building are measured and adjusted to comply with stipulated levels. This means that

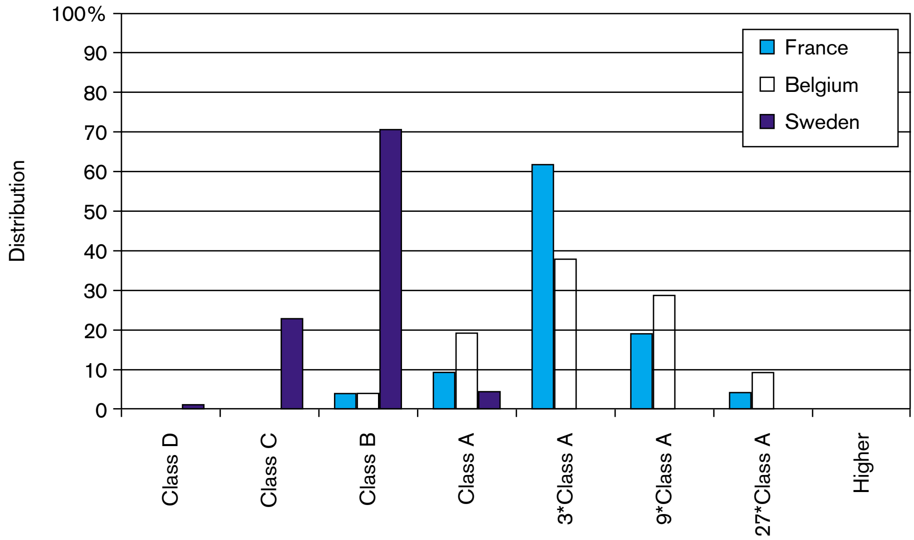

FIGURE 13. Distribution of the different airtightness classes based on measurements carried out in 21 systems in Belgium, 21 Systems in France and 69 systems in Sweden. The bars represent the relative number of systems fulfilling the requirements for the specified airtightness class.

a duct system must be planned and installed in such a way that this work can be carried out with acceptable accuracy and at the lowest possible costs.

The shorter the distance that the air has to be transported between the fan and the terminal devices, the less energy will be required and the simpler the balancing work will be. The balancing work will also be simplified, and the energy use less, if the system is designed so that the air flows to the terminal devices are supplied via symmetrically branched distribution networks rather than via terminal devices placed in series.

This means that ducts supplying several terminal devices should be divided into branch ducts and stub ducts. If several terminal devices are connected to one and the same duct, then the distance between the first and the last terminal device must be made as short as possible, to avoid excessive damping and noise from the devices.

Placing the devices symmetrically is something that will greatly simplify and shorten the time required for balancing. The ductwork between the main duct and the terminal devices will be built up in the same way, using the same types of duct components and duct lengths, which means that the air pressure at each terminal device will be the same. See Chapter 29/Balancing ventilation systems.

Why clean them?

CLEANING VENTILATION DUCTS

There are three main reasons why ducts should be kept clean:

1. Pollutants can restrict air flows to such an extent that the ducts cease to function properly; pressure drops will rise and air flows decrease.
2. The inside walls of the ducts can become coated with a layer of combustible pollutants; these might ignite and cause fires or explosions.
3. Pollutants that are irritants, or that are otherwise dangerous, can collect in the ducts and cause health damage if introduced into occupied rooms.

The first reason is especially applicable to extract air ducts from wet rooms, where small dimension ductwork can easily become blocked. Extract air is warm and humid, and vapour will condense on the inside of the cold metal ductwork. Fibre particles in the extract air, from washing hung to dry and from wet towels, will then stick to this wet surface. Extract air terminal devices are normally connected to 80 mm ducts and these cannot cope with any large build-ups of pollutants before the air flows become insufficient. As these fibre particles collect along the first 50 cm of a duct, they are easy to remove.

The second reason concerns ducts used to remove inflammable or explosive pollutants, i.e. ducts that must be cleaned regularly according to the requirements stipulated in national fire prevention regulations. There are numerous uses of ducts where these regulations are applicable: in extraction systems for paint spraying booths, bakery ovens, kitchen ranges and deep-frying units where the primary objective is to prevent pollutants from entering the ducts, for example, by using paint and fat filters.

When designing and installing ducts like these, it is important to follow the national fire regulations very carefully. Plans must be drawn up which describe how cleaning is to be carried out, where the inspection and cleaning hatches are to be placed and whether the ducts are to be fitted with internal cleaning devices. Care must be taken to choose the correct duct materials, thicknesses and types of insulation, and to stipulate safe distances to combustible parts of the building.

The third reason must be explained in more detail. It is the most recent of the three reasons and has been discussed for the last two decades as a way of reducing the risk of SBS, Sick Building Syndrome, and improving the quality of the indoor air.

It goes without saying that pollutants from soiled ducts must not be allowed to foul the supply air. If there is a risk of this happening, it must be eliminated by cleaning the ducts. These risks can occur in supply air ducts if the filters are of inferior quality, if they are overloaded or if they are installed so that unfiltered air can bypass the filter.

There is a risk that ducts can become breeding grounds for mould and fungi. The best way to prevent this is to:

- Avoid letting the ducts become wet by:
  - using the right types and designs of air intake grilles
  - limiting the speed of the air through the intake to a maximum of 2.5 m/s.

  Both these measure will reduce the risk of the supply air drawing rain drops and snow flakes into the ventilation system, see Chapter 18/ Outdoor air intakes – location, design, inspection and cleaning.
- Locate the outdoor air intake where the air is cleanest, see sub-section *Locations for fans and air handling plant* above.
- Refrain from insulating the ductwork on the inside.
- Inspect the intake ducts regularly to check whether they need to be cleaned. Inspection and cleaning hatches will be needed.
- Design the intake duct so that any moisture can run off to a drainage point.

Cleanliness checks, and cleaning when necessary, are carried out regularly in many countries, even if they are not stipulated in official regulations. It is therefore a good idea to mark out the size and position of inspection and cleaning hatches on the relevant drawings.

Which ducts need cleaning?

If the ducts have to be cleaned for reasons of health and comfort, then it should be possible to limit cleaning to the supply air ducts, at least in countries where, for reasons of hygiene, return air is not used.

If return air is used, it must be ensured that the extract air does not carry tobacco smoke or undesirable smells to the air handling unit and thereby impair the quality of the supply air. If return air is used, then the extract air and return air ducts should, of course, be inspected and, if necessary, cleaned.

The reasons for cleaning ducts, as shown above, apply to all pollutants introduced into the ducts after installation. However, it is not always necessary to clean all the duct systems in a building, if only one of the systems is shown to require cleaning. Table 5 summarizes the most common and important reasons for cleaning different types of duct systems.

Table 5. Which ducts should be cleaned and why?

Which ducts should be cleaned?	Why should they be cleaned?		
	Function	Fire risk	Health
Extract air ducts in dwellings, offices and schools	x	–	–
Return air ducts in dwellings, offices and schools	x	–	x
Supply air ducts in dwellings, offices and schools	–	–	x
Supply air ducts in dwellings, offices and schools with return air	x	–	x
Extract air and special extraction ducts in industrial premises	x	–	–
Cleaning required by law, because of fire risks	x	x	–

x normally required. – seldom required.

Make sure that all ducts are clean from the start!

It is important to keep ventilation ducts clean at every stage in the building process, i.e. while transporting them to the building site, during the installation work and until the system is put into operation. It is now becoming increasingly more common to protect the open ends of the ducts with tight-fitting covers of plastic or cardboard.

When protective solutions are needed, it is important that the requirements are stipulated in the contract documents, for example, according to one of the following alternatives:

Table 6. Protection levels and end cover requirements.

Protection level	After manufacture	During transportation	While storing on site	During installation
0	No	No	No	Yes, but only vertical ducts*
1	No	No	Yes	Yes
2	Yes	Yes	Yes	Yes

* In winter, vertical ducts can act as flues, allowing thermal forces to draw polluted air up through the building.

If ducts are not protected against interior soiling, the system must be cleaned before being put into operation for the first time. Checking duct cleanliness should be a natural part of the final building inspection.

When is cleaning needed?
The need for cleaning is normally determined by visual inspection. This can be done by using TV inspection equipment, or manually and visually by using torches and mirrors inserted into the ducts via the inspection hatches, which means that these should be situated relatively close together.

When TV inspections are carried out, a small camera is mounted on a remotely controlled robot that can work its way through the duct system. The camera then transmits a signal to a monitor and video recorder. The distance that the camera has travelled is shown on the screen to pinpoint where any special steps need be taken. As this type of equipment is relatively expensive and requires skilled operators, the work is normally carried out by a specialist contractor.

Duct cleaning methods
The methods used are:
- Dry cleaning
- Wet cleaning
- Disinfection
- Encapsulation
- Removal of insulation linings

Dry cleaning is used when the pollutants can be removed using simple mechanical tools or when the use of water is not appropriate.

Manual cleaning and swabbing is used when it is easy to access the insides of the ducts or when these are so large that the cleaner can get inside them. If this is possible, it is extremely important that the strength of the suspension system is checked first. Supports must be designed so that they can carry the extra weight of the cleaner as well as tools and equipment. For manual cleaning, from both the outside and the inside, sufficiently large cleaning hatches or manholes will be required.

Small ducts can be cleaned using tools fitted with rotary brushes and special mouthpieces for cleaning agents. Chemicals can then be used to kill off organisms or limit their growth.

This method normally entails isolating a section of the duct system and subjecting it to an under-pressure by attaching a vacuum cleaner to one end of the section. The vacuum cleaner used to create the under-pressure and collect the pollutants must be fitted with a HEPA filter. The cleaning process starts at the far end of the section and progresses towards the extraction end. Different types of visual monitoring are used to check the results.

If the ducts are lined with insulation, then encapsulation, i.e. internal duct sealing or re-lining, can be used to prevent the erosion of fibres from the insulation material and thereby contain the organic substances that could form a breeding ground for microorganism growth. However, for best results, it is often best to remove the insulation material, if this is at all possible.

Occupants in a building must be protected during the cleaning work by completely isolating the duct sections that are being cleaned from the air handling equipment and from the rest of the building.

The use of decontaminants and chemicals when encapsulating is more difficult. The substances must be approved for use and the cleaners must be dressed in suitable protective clothing and equipped with breathing apparatus or, in less dangerous cases, with protective face masks.

The effectiveness of different cleaning methods is not very well documented. The methods used to judge the results vary – from scraping samples from the cleaned surfaces to the use of agar plates to check for microbial presence – and the results are not mutually comparable.

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