Duct and Piping Guideline

May 2011

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1 Introduction
In most installations, the constraints imposed by the building or other structures, and the siting of pumps and fans, emitters and plant items and terminals, can lead to the adoption of an overall duct and piping layout which is not energy efficient.

The performance of a system can also be adversely affected by a lack of care and thought in the arrangement and detailing of the pipe and duct work. The designer and installer should be aware of the characteristics of water and airflow in pipes, ducts and fittings so that the objectives of the design are compromised as little as possible by the constraints imposed and by space restrictions. In general, good design should ensure that the air velocities are relatively uniform and fluid flows low and well balanced and that the total system pressure loss is minimised. These factors will lead to lower operational energy consumption, and requirements set in the Energy Efficiency Building Code can easier be met.

The site will often dictate the main routing of pipe and duct work systems but in general the design should seek to make the layout as symmetrical as possible; the pressure loss in each branch should be as nearly equal as possible. This will aid regulation and may reduce the number and variety of duct fittings and regulation valves that are needed.

The number of fittings should be kept to a minimum and there should be a conscious attempt to achieve some standardisation of types and sizes.

Increasing the numbers and variety of fittings in a system can markedly raise its overall cost and increase pressure loss.

The shorter the pipe and duct work length, the lower is the pressure drop and consequently the energy consumption for operation. Distribution lengths are influenced by:

- The shape of the building
- The number and location of emitters and system plant rooms
- The provision of space for distribution.

In large buildings or industrial plants a choice between a single distribution system and multiple smaller systems may arise. Large distribution systems and their plant can have the advantage of lower operating costs but require more floor space for vertical shafts. In general, very long runs of ducting and piping should be avoided to prevent undue thermal losses or gains, excessive leakage and difficulties in balancing during commissioning.

Also, the pressure losses in long runs are likely to be higher. Multiple smaller distribution systems may be more expensive in capital and operating costs but they avoid long runs, large ducts and pipes and vertical shafts, and this may reduce overall building costs.

Finally, pipes and ducts should be properly insulated. This will not only help reducing heating and cooling costs but also make the indoor environment more comfortable.

Denmark, Mauritius, December 2010
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2 Symbols

\( A \)  
Cross-section area of duct \((m^2)\)

\( A_s \)  
Duct/pipe surface area \((m^2)\)

\( P \)  
Perimeter of the duct/pipe cross section \((m)\)

\( P_f \)  
Fan power \((W)\)

\( c \)  
Velocity \((m/s)\)

\( c_p \)  
Specific thermal capacity (at constant pressure) \((kJ/g*K)\)

\( d \)  
Diameter \((m \text{ or } mm)\)

\( k \)  
Equivalent roughness \((mm)\)

\( l \)  
Length \((m \text{ or } mm)\)

\( p \)  
Pressure \((Pa)\)

\( q_v \)  
Volume flow \((m^3/s \text{ or litre/s})\)

\( \Delta p \)  
Pressure difference \((Pa)\)

\( \Delta p_{tot} \)  
Total pressure loss in the system \((Pa)\)

\( \Delta p_f \)  
Pressure loss due to friction in pipes/ducts \((Pa)\)

\( \Delta p_t \)  
Pressure loss due to fittings, bends etc \((Pa)\)

\( \zeta \)  
Pressure loss factor

\( \rho \)  
Density \((kg/m^3)\)

\( P_{sf} \)  
Specific fan power \((Ws/litre)\)

\( t \)  
Temperature \((^\circ C)\)

\( t_{ad} \)  
Temperature of air/liquid in duct/pipe \((^\circ C)\)

\( t_{as} \)  
Temperature of air around the duct \((^\circ C)\)

\( t_{ad1} \)  
Temperature of air/liquid in the upstream end of the duct/pipe run \((^\circ C)\)

\( t_{ad2} \)  
Temperature of air/liquid in the downstream end of the duct/pipe run \((^\circ C)\)

\( h_{si} \)  
Heat transfer coefficient of the inside surface of the duct/pipe \((W/(m^2\cdot K))\)

\( d_i \)  
Insulation thickness \((m)\)

\( h_{so} \)  
Heat transfer coefficient of the outside surface of the duct/pipe \((W/(m\cdot K))\)

\( \Delta t \)  
Temperature difference \((K)\)

\( \lambda_i \)  
Thermal conductivity of the insulation \((W/(m\cdot K))\)

\( U \)  
Overall thermal transmittance \((W/m^2K)\)

\( \Phi \)  
Heat exchange \((W)\)

\( C_o \)  
Flow velocity \((m/s)\)

\( s \)  
Pipe thickness \((m)\)

\( \rho_R \)  
Density of fluid \((kg/m^3)\)

\( P_r \)  
Investment cost for piping \((\text{cost/kg})\)

\( P_E \)  
Energy price \((\text{cost}/(W*s))\)

\( \lambda \)  
Friction factor \((-)\)

\( q_v \)  
Volume flow \((m^3/s)\)

\( t \)  
Operation hours \((s/\text{installation})\)

\( \eta \)  
Pump total efficiency \((-)\)

\( a \)  
Present value factor, \( a = (1+r)^n*r/((1+r)^n-1)\)

\( n \)  
Number of installments

\( r \)  
Interest rate

\( V_E \)  
Volume of expansion vessel \([L]\)

\( V \)  
Volume \([L]\)

\( p_s \)  
Safety valve opening pressure \([\text{bar}]\)

\( p_e \)  
Expansion vessel prepressure \([\text{bar}]\)
3 Building services interaction with building form

3.1 Process of change – historical reflection

Through the years there has been an expansion in scope of the technical installations, which is associated to the improvements in the building's functionality. This evolution in the interaction between unfinished buildings and technology can be described from both theoretical and empirical considerations.

3.1.1 Theoretical considerations

The civilization's development is closely associated with the exploitation of massive buildings that have been good at creating space and meet people's basic requirements for indoor environments. Our architectural and constructional traditions are thus based on a cultural discourse that prioritises the building shell to create indoor environments. But with industrial society's development came a series of technological advances and new industrial products, which enabled the design of new building types with a satisfactory indoor environment without the traditional limitations.

This trend in the technical equipment has opened up an extended functionality in buildings with particular innovative new work processes and intelligent systems that have resulted in the development of modern building types. This gives a contradiction. While it is building massive and material qualities, priorities and highlighted in the Western cultural discourse, it is the technical installations, which are typical prefabricated industrial products that will produce the new functionality.

3.1.2 Empirical considerations

The historical development shows that a requirement on new functionality is achieved through a gradual expansion in scope of the technical installations. Technological developments and a clear functional specialization in the years after 1950 means that one can usefully focus on, respectively office and home development. For both these types of buildings, results show that building services proportion of total expenditure, craftsman costs and the total time spent on the construction site has become significantly larger over the past 50 years.

3.1.3 The development

Historically, the vertical duct and piping routes have been concentrated in building service zones where the most demanding installation features were located, a decision that gave many functional and economic benefits, which was reflected in modern architecture and the industrialized construction. Functional and innovative changes have however created a new set of conditions where it is
now typically in the building’s other zones, the new installation demanding functions exist. The results for both home and office developments show that this functional change, is pointing in the direction of new intelligent building typologies with decentralized service zones. Recent research also shows that there may be many construction and operational benefits of a decentralization of engineering vertical routes.

3.2 Aesthetics of the building
Where pipe and duct work is hidden in risers, ceiling voids and below the floor will not have an effect on the visual environment. In some situations, ducts can be large (e.g. 1–2 m in diameter) and difficult to locate within the overall building design. In such circumstances the duct work may be exposed and possibly made an architectural feature. The design, including the shape, location and visual appearance will need to be addressed to ensure sympathy with the visual environment.

Shopping centres, airports, auditoria, display galleries and large office complexes are possible examples where exposed pipe and duct work may be used. Installation standards and sealing systems for such pipes and ducts may require more attention to the final appearance of the duct system than with pipes and ducts in concealed spaces.

Centre Georges Pompidou, designed by the Italian architect Renzo Piano in 1977. Its exposed skeleton of brightly colored tubes for mechanical systems turned the World Architecture “up-side down”.

3.4 An Integrated Design Process

The structural design in a building may have reached beyond an outline design and shape by the time that pipe and duct work design commences. It is usually possible to accommodate vertical ducts and pipes of any desired size without great difficulty from both structural and planning viewpoints. Horizontal ducts and pipes present more problems. If they are located between floors, headroom will be restricted and there will be limits on the floor area which a horizontal duct or piping system can serve. Early checks should be carried out to ensure that the vertical main ducts and pipes enable horizontal distribution without compromising the performance of the installation or the available headroom and that structural members allow branch ducts and pipes to leave the main routes.

Distribution of the engineering services within a building are likely to follow a pattern associated with the main building circulation route which represents the main functional pattern of the building. This may not be the most efficient route for the pipe and duct work. The large space requirements for especially duct work mean that it can be desirable to locate plant close to the areas they serve.

Because duct work is likely to be the most space intensive service provided, it is important that the duct work design is fully co-ordinated with the design of the building structure and other installations to minimise the number of bends and other fittings, each of which will increase the resistance to air flow. This is particularly important for new installations for which the Energy Efficiency Building Code sets down strict requirements for maximum specific fan power.

Sufficient space needs to be provided for ease of fitting the pipe and duct work. Providing access for maintenance is also important since it will be expensive to install retrospectively, whether ducts are horizontal or vertical.

Space should also be allowed for additions and alterations. Co-ordination of the engineering services should ensure that the area for removal of access panels and covers and entry into the pipe and duct work is free of services and readily accessible without obstructions.

The figure below outlines the design process for typical pipe and duct work designs.
Designing pipe and duct systems is an integrated design process.
4 Flow in pipes and ducts

4.1 Introduction

Pipe and duct sizes should ideally be selected to achieve minimum life cycle cost, taking account of both capital cost of pumps and fans and the running cost to provide the pumping or fan power required.

4.2 Pressure loss in pipes and ducts

Losses in a piping and duct system are typically categorized as major and minor losses. Minor losses in piping and ducts are generally characterized as any losses which are due to inlets and outlets, fittings and bends, valves, expansions and contractions, filters etc. Essentially, everything within the system which is not a section of the pipe or duct or other major component. In fact, in many flow systems the minor losses can account for more head loss, than the straight pipe and ducts themselves.

Major losses of head in a piping or duct system are the direct result of fluid or air friction. The resulting head losses are usually computed through the use of friction factors. Friction factors for ducts have been compiled for both laminar and turbulent flows.

Minor losses in systems are most often calculated using the concept of a loss coefficient or equivalent friction length method.

Total pressure loss in pipes and ducts

This section gives the basic principles for predicting the pressure drop in pipes and ducts.

The total pressure drop is given as:

$$\Delta p_{\text{tot}} = \Delta p_f + \Delta p_\xi$$  \hspace{1cm} (4.1)

Where:

- $\Delta p_{\text{tot}}$ is the total pressure loss in the system (Pa)
- $\Delta p_f$ is the pressure loss due to friction in pipes/ducts (Pa)
- $\Delta p_\xi$ is the pressure loss due to fittings, bends etc (Pa)

The D’Arcy equation for pressure loss due to friction may be given as:

$$\Delta p_f = \lambda \cdot \frac{1}{d} \cdot \frac{1}{2} \cdot \rho c^2$$  \hspace{1cm} (4.2)

Where:

- $\lambda$ is the friction factor, and may be obtained mathematically or from a Moody chart and depends upon the values of Reynolds number, Re, and relative roughness k/d (-)
- $l$ is the length of the pipe/duct (m)
- $\rho$ is the density of fluid/air (kg/m$^3$)
- $c$ is the velocity (m/s)

Values for roughness can be found in appendix 4.

The equation for pressure loss due to fittings, bends etc. may be given as:

$$\Delta p_\xi = \frac{1}{2} \rho c$$  \hspace{1cm} (4.3)

Where:

- $\xi$ is the pressure loss factor. Data for ductworks and pipes can be found in other literature (-)
- $\rho$ is the density of fluid/air (kg/m$^3$)
- $c$ is the velocity (m/s$^2$)

Elaborated calculation guidance of pressure losses in ducts and pipes is handled in fundamental literature, such as ASHRAE Handbooks: Fundamentals and...
5 Thermal gains or losses in pipes and ducts

In a piping and duct system, the air and water temperature change can be significant, e.g. when passing through an untreated space. This has the effect of reducing the heating or cooling capacity of the air or fluid and increasing the energy input to the system. The heat transmission to and from the surrounding space can be reduced by insulation of the ducts.

The benefits include, in addition to reducing costs and environmental impacts of energy consumption:

- Reducing or eliminating condensation on cold pipes and ducts.
- Protection from dangerous pipe temperatures.
- In domestic hot-water systems, the water temperature at the point of use can be closer to the temperature at the water heater, and wait time for hot water can be reduced
- Control of noise.
- Reduction of unwanted heat gain to air-conditioned spaces.

The mean temperature of the medium inside the duct/pipe is given by:

\[ t_{ad} = \frac{1}{2}(t_{ad1} + t_{ad2}) \]  (4.5)

Where:
- \( t_{ad1} \) is the air or fluid temperature in the upstream end of the duct/pipe run (°C),
- \( t_{ad2} \) is the air or fluid temperature in the downstream end of the duct/pipe run (°C).

The duct or pipe surface area is given by:

\[ A_s = P \cdot l \]  (4.6)

Where:
- \( A_s \) is the duct/pipe surface area (m²),
- \( P \) is the perimeter of the duct/pipe cross section (m),
- \( l \) is the length of the duct/pipe run (m).

Ignoring the thermal resistance of the pipe and duct material, the \( U \)-value of the insulated duct/pipe is given by:

\[ U = 1/(1/h_{si} + d_n/\lambda_n + 1/h_{so}) \]  (4.7)

Where:
- \( h_{si} \) is the heat transfer coefficient of the inside surface of the duct/pipe \((W/(m^2\cdot K))\),
- \( d_n \) is the insulation thickness (m),
- \( \lambda_n \) is the thermal conductivity of the insulation \((W/(m\cdot K))\).
\( h_{so} \) is the heat transfer coefficient of the outside surface of the duct/pipe (W/(m·K))

For most typical applications, \( h_{so} \) may be taken as 37.5 W/(m²·K). The value of \( h_{so} \) also depends on the conditions surrounding the duct or pipe. A typical value for unvented building voids is 10 W/m²·K, but this can be influenced by reflective facing materials on the insulation and by draughts.

In Annex 1 recommended minimum thickness of insulation are given for ductworks and pipes.

### 5.1 Extent of insulation

The following ducts and pipes should be insulated:

- All supply air ductwork
- All return air ductwork located above the ceiling immediately below the roof should be insulated.
- Any chilled or heated main supply piping
- Any ductwork and piping outside the building envelope
- All exhaust and relief air ductwork between the motor-operated damper and penetration of the building exterior should be insulated.
- Insulation should include a vapor retardant on the outside of the insulation where condensation is possible.

In conditioned spaces without a finished ceiling, only the supply air duct and pipings mains and major branches should be insulated. Individual branches and runouts to diffusers/heaters/coolers in the space being served do not need to be insulated, except where it may be necessary to prevent condensation.

Small pipes can be insulated with cylindrical half-sections of rigid insulation or with preformed flexible material. Larger pipes can be insulated with flexible material or with curved, flat segmented or cylindrical half, third, or quarter sections of rigid insulation. Fittings (valves, tees, crosses, and elbows) may use preformed fitting insulation, fabricated fitting insulation, individual pieces cut from sectional straight-pipe insulation, or insulating cements. Fitting insulations should always be equal in thermal performance to the pipe insulation.

Ducts can be insulated with glass fiber, and plastic or foil backing is often used around duct connections and plenums. Can also be laid on the attic floor; they are then surrounded by cardboard channels and cellulose insulation in blown in around and over the ducts.

![Figure 3. Pipes with cylindrical half-sections](image)

![Figure 4. Duct insulation](image)
5.3 Insulation materials

Insulation materials may be categorized into one of five major types 1) Cellular, 2) Fibrous, 3) Flake, 4) Granular, and 5) Reflective.

Cellular insulations are composed of small individual cells either interconnecting or sealed from each other to form a cellular structure. Glass, plastics, and rubber may comprise the base material and a variety of foaming agents are used.

Fibrous insulations are composed of small diameter fibers that finely divide the air space. The fibers may be organic or inorganic and they are normally (but not always) held together by a binder. Typical inorganic fibers include glass, rock wool, slag wool, and alumina silica. These materials are sometimes supplied with coatings or as composites for specific properties, e.g. weather and chemical resistance, reflectivity, etc.

Flake insulations are composed of small particles or flakes which finely divide the air space. These flakes may or may not be bonded together. Vermiculite, or expanded mica, is flake insulation.

Granular insulations are composed of small nodules that contain voids or hollow spaces. These materials are sometimes considered open cell materials since gases can be transferred between the individual spaces. Calcium silicate and molded perlite insulations are considered granular insulation.

Reflective Insulations and treatments are added to surfaces to lower the long-wave emittance thereby reducing the radiant heat transfer to or from the surface.

6 Testing and commissioning

All duct work and piping systems should be tested and commissioned and also be leak tested. The needs of on-site regulation should be planned and provided for in the design stage, otherwise balancing the system within acceptable limits may not be possible.

The designer must accept the implications of the commissioning procedures to which the air and water distribution system will be subjected. Inadequate commissioning will result in poor environmental performance, energy wastage and for duct work in draughts and noise. The measuring, regulating and apportioning of air and water flow in a distribution system are a means to an end. The objective is to ensure that the performance of the commissioned installation is adequate to maintain the specified environmental conditions of the space with optimum efficiency.

7 Pipe work

7.1 Introduction

The hydraulic requirements for a pipe work system are derived from parameters such as system operating temperature and the cooling or heat output required from emitters, which affect the layout. The design also needs to take account of the effect of water velocity on noise and corrosion, and the pressure and flow characteristics required of the circulation pump.

The key design decisions include:
• System pressures
• Whether to use an open or a sealed pressurization method
• Which material to use for pipes
• The flow velocity to be used
• How the system is to be controlled
• How to balance the system
• How to obtain an energy and cost effective operation
• Filling and air removal arrangements
• Pumping requirements, i.e. variable or fixed flow rate.

The designer has considerable flexibility in choosing appropriate pipe sizes. A larger pipe diameter reduces the friction pressure drop and hence the pump power needed to achieve the design circulation. Even a small increase in diameter can have a significant effect, as the pressure drop is approximately proportional to the fifth power of diameter for the same mass flow.

7.2 System layout and design

Systems must be designed to match their specified design heat or cooling load, including domestic hot water provision where required, and to have controls capable of matching output to the full range of variation in load over a heating season.

Separate circuits may be required to serve zones of the building with different requirements. In addition, there must be provision for hydraulic balancing of circuits and sub-circuits, and for filling, draining and venting of each part of the system.

Distribution systems may be broadly grouped into one-pipe and two-pipe categories. In one-pipe systems, emitters are effectively fed in series, and system temperature varies around the circuit. Control of one-pipe systems requires the use of by-passes and 3-port valves. Two-pipe systems operate at nominally the same temperature throughout the circuit but require good balancing for that condition to be achieved in practice. Control of two-pipe systems may employ either 2-port or 3-port valves to restrict flow to individual emitters.

7.3 Hydraulic design

Hydraulic design needs to take account of the effect of water velocity on noise and erosion, and of the pressure and flow characteristics of the circulation pump. Tables showing pressure loss against flow rate for common pipe sizes and materials can be found in basic literature.

Flow velocities may be determined by consideration of pressure drops per meter of pipe run (typically in the range of 100 to 350 Pa/m). Alternatively, flow velocities may be considered directly, usually to be maintained in the range 0.75 to 1.5 m/s for small-bore pipes (<50 mm diameter) and between 1.25 and 3 m/s for larger pipes.

Pumps should be capable of delivering the maximum flow required by the circuit at the design pressure drop around the circuit of greatest resistance, commonly known as the index circuit. If variable speed pumping is to be used, the method of controlling pump speed should be clearly described and the pump should be sized to operate around an appropriate part of its operating range.

For pumps the overall efficiency of the combined unit including the motor and the drive coupling is what matters. Pump characteristics obtained from manufacturers should be used to choose the pump which operates around the point of maximum efficiency. Pumping energy consumption cost can be
considerable and may be a significant proportion of total running costs in some systems. Where a wide flow range is required multiple speed or variable drive speed should be considered.

The location and sizing of control valves need to take account of pressure drops and flows around the circuit to ensure that they operate with sufficient valve authority.

7.4 Pressure loss factors
As mentioned earlier, the predominant source of friction pressure drop in pipes and has traditionally been attributed to the flow separation and vortices downstream of an elbow or bend. However, surface effects play an important part, the pressure drop being very dependent upon the surface roughness and shape of the inner surface. Thus it is found that the values of $\zeta$ depend upon the diameter and the material. Since even a small change in the internal shape of a pipe fitting can cause an appreciable difference in friction effects, it is clear that for small diameters, the pressure loss factor could also be manufacturer-dependent.

The pressure drop calculated for a component is always to be added to the pressure drop of the full length of the pipe work or duct work.

7.5 Balancing
The objective of balancing is to ensure that each emitter receives the flow required at the design temperature. Balancing may be carried out most precisely by measuring and adjusting flow to individual parts of the circuit, but can also be carried out by observing temperatures throughout the system.

Temperature-based balancing is commonly used on domestic systems but has the disadvantage that the adjustments must be made and checked when the system has reached a steady-state, which may take a considerable time. It is important to take account of the need for balancing at the design stage, including the location of measuring stations around the system, the equipment needed to achieve balancing, and the procedures for carrying it out.

Balancing by flow requires a provision for flow measurement and, in all cases, appropriate valves must be installed to control the flow to particular parts of the circuit. Balancing procedures, including a technical specification for commissioning the system, and the responsibilities of the various parties involved should be clearly identified at the outset.

The design of pipe work systems can have a considerable effect on the ease with which balancing can be achieved.

Reverse return circuits, which ensure that each load has a similar circuit length for its combined flow and return path, can eliminate much of the inequality of flow that might otherwise need to be rectified during balancing.

Distribution manifolds and carefully selected pipe sizes can also assist with circuit balancing. It is important to avoid connecting loads with widely differing pressure drops and emitting characteristics to the same sub-circuit.

Detailed guidance on commissioning may be found in other fundamental literature.

7.6 Pipe sizing
There are no rules concerning pipe sizing. The most cost effective will be the design based on life-cycle costing
including the pumping costs. The smaller the pipework, the greater the pumping power and energy consumption.

Increasing the pipe diameter by one size can have a large effect in decreasing pumping power: smaller friction pressure drops of the basic circuit will require smaller pressure drops through control valves, for the same value of valve authority. The optimum sizing from the point of view of life-cycle costing must consider the following:

- Length of the system,
- The capital cost,
- The mean pressure drop,
- The running time at full and partial flow,
- The efficiency of the pump–motor combination,
- Anticipated electrical tariffs (i.e. ‘on-peak’ or ‘off-peak’ operation).

Once the emitters have been selected and the design flow and return temperatures decided, the circulation requirements in each part of the circuit can be determined. Pipe sizes for individual parts of each circuit may then be selected to give acceptable pressure drops and flow velocities.

Consideration should also be given at this stage to the compatibility of emitters connected to particular circuits and to how the system can maintain balance as flow is restricted by control valves.

### 7.6.1 Desirable velocities

In practice, the starting point for pipe sizing is usually based on flow velocity. Table 1 shows some typical water velocities for piping.

![Table 1. Recommended maximum water velocities for piping.](image)

### 7.6.2 Desirable pressure drop in straight pipes

Another approach is to size for a particular pressure drop per unit length, typically between 50 to 350 Pa/m, depending on the system size.

Steel pipes and plastic pipe has no physical limitations in permissible pressure loss, but the copper pipes applies to the below velocities, in order to avoid corrosion due to turbulent shell.

Generally, the guidelines in Table 2 can be followed for all types of pipes. In appendix 5 pressure drop chart can be found,

<table>
<thead>
<tr>
<th>System size</th>
<th>Max. pressure loss (Pa/m)</th>
<th>Max. velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller systems</td>
<td>50 - 100</td>
<td>v = 0,5 – 1,5</td>
</tr>
<tr>
<td>Medium systems</td>
<td>100 - 200</td>
<td>v = 1,0 – 2,5</td>
</tr>
<tr>
<td>Larger system</td>
<td>200-350</td>
<td>v = 1,5 – 3,5</td>
</tr>
</tbody>
</table>

Table 2. Recommended maximum pressure losses in straight pipes.

The energy savings by increasing the pipe dimensions should always be weighed against the additional cost associated with use of a larger pipe.
dimensions.

Special fittings rises in price with increased diameter and especially stainless steel pipes and fittings can cause significant additional costs resulting from increasing pipe dimensions.

Piping must be performed energy conscious and total economic optimum.

The relationship of volume flow, pressure drop and power requirement to pump can be illustrated as:

\[ \frac{1}{2} q = \frac{1}{4} \Delta p_{\text{tot}} = 1/8 \ P \quad (7.1) \]

Where:

- \( q \) is the volume flow (m\(^3\)/s)
- \( \Delta p \) is the total pressure drop in the piping system (Pa)
- \( P \) is the pump power (W)

Example: Pipe sizing.
In this example system size can be categorized as a medium system.
According to table 2 the maximum pressure loss is 100-200 Pa/m. The flow is \( q = 20 \text{ l/s} \) and the pipe material is black steel. From appendix 6 figure 1 the pipe size and the pressure drop can be obtained. Nominal pipe size is 125 mm and the actual pressure drop is 180 Pa/m.

### 7.7 Cost efficient pipe sizing

The basic principle by sizing pipes is that the system apart from meeting the technical requirements also must cause the least possible annual costs.

The annual costs include return of investment; system operating costs for pumping and for certain pipes energy loss due to thermal losses to surroundings.

The investment increases with pipe diameter while the pressure loss decreases. This can be illustrated in Figure 5, where \( a \) is the operating costs due to pressure loss and \( b \) is the investment cost. Where \( a + b \) is at least, the most cost efficient pipe diameter \( d_e \) is found.

![Figure 5. Recommended maximum pressure losses in straight pipes.](image)

If the pipe diameter must be chosen so that the total cost for investment and operation minimal, the following equation for the most cost efficient velocity can be used:

\[ C_v = \sqrt[3]{\frac{16 \cdot s \cdot \rho_R \cdot P_E \cdot a_n \cdot r \cdot \eta}{s \cdot \lambda \cdot \rho_R \cdot v \cdot t \cdot P_E}} \quad (7.2) \]

Where:

- \( C_v \) is the flow velocity (m/s)
- \( s \) is the pipe thickness (m)
- \( l \) is the pipe length (m)
- \( \rho_R \) is the density of fluid (kg/m\(^3\))
- \( P_r \) is the investment cost for piping (cost/kg)
- \( P_E \) is the energy price (cost/(W*s))
- \( \lambda \) is the friction factor (-)
- \( q_v \) is the volume flow (m\(^3\)/s)
- \( t \) is the operation hours (s/installment)
- \( \eta \) is the pump total efficiency (-)
- \( a_{n,r} \) is the present value factor, \( a = (1+r)^n \cdot r / ((1+r)^n - 1) \)
- \( n \) is the number of installments
- \( r \) is the interest rate
Table 3 shows that energy consumption is high by long operation times, so it is often cost effective to choose pipes with low velocity.

The column with maximum pressure loss reflects the energy consumed to transport 1 m³ of water 1 m along the pipe. For a given flow velocity the pressure loss (and thus energy consumption) is greater for a small pipe than for a large pipe.

<table>
<thead>
<tr>
<th>Annual operating hours</th>
<th>Dimension (mm)</th>
<th>Max. velocity (m/s)</th>
<th>Max. pressure drop (Pa/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 4000</td>
<td>0 - 100</td>
<td>1,0</td>
<td>250</td>
</tr>
<tr>
<td>0 - 4000</td>
<td>&gt; 100</td>
<td>1,4</td>
<td>150</td>
</tr>
<tr>
<td>4000 - 8760</td>
<td>0 - 100</td>
<td>0,7</td>
<td>200</td>
</tr>
<tr>
<td>4000 - 8760</td>
<td>&gt; 100</td>
<td>1,0</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3. Recommended flow velocities related to annual operating hours.

7.8 Noise generation in pipes

With small pipes, excessive velocities can lead to noise generation where, with hot water, cavitations may occur at elbows, valves, pumps and especially orifice plates.

In this respect larger pipes should be able to tolerate higher velocities without a noise problem. Similarly higher velocities are possible with polymer piping due to the noise absorption effect of such piping.

Noise problems are more likely to occur if entrained air is not separated and vented. Arrangements should be made so that this is achieved easily. An up stand and air vent at the top of each vertical run of pipe is recommended; during pump-off periods, entrained air will separate out into the higher position. This will simultaneously reduce corrosion by eliminating oxygen as soon as possible.

7.9 Allowances for ageing

Corrosion and scaling of the internal diameter of pipe work will occur with age depending on the chemical composition of the water. This will increase the surface roughness of the pipe and decrease the internal diameter, both of which will increase the friction pressure drop. No firm recommendation can be made on the allowance to be made. A large allowance is more justifiable with small diameter pipes. Open systems will suffer more than closed systems. Often an increase of 15 to 20% in the friction factor $\lambda$, compared with new pipe work is seen in closed systems. For open systems, there could be a 75% increase. Studies also show that there is little corrosion with plastic pipe.

7.10 Water hammer

Large pressures can arise when the fluid flow is stopped abruptly by the sudden closure of a valve. This pressure wave then reverberates within the pipe work. The magnitude of the pressure wave is in proportion to the momentum of the flowing fluid and thus to its velocity.
7.11 Water expansion

Between a system being cold or warm (usually under the ‘fill’ situation), and warm or cold under the design running condition, the water contained in the system will expand.

The volumetric expansion of the pipe work may be deduced from the volumetric expansion of the water, if desired. Pre-calculated values for the expansion of water are given in Table 4.

An expansion vessel can be designed from equation 7.1. The equation applies to central heating, boilers etc. in closed systems.

\[
V_E = \frac{(0.07 \times t - 2.5) \times (p_s + 1)}{100 \times (p_s - p_e)}
\]  

(7.1)

Where:

- \(V_E\) is the volume of the expansion vessel [litre]
- \(V\) is the total volume of the system [litre]
- \(t\) is the temperature where boiling terminates the heating. [°C]
- \(p_s\) is the safety valve opening pressure [bar]
- \(p_e\) is the pre-pressure of the expansion vessel [bar]

A higher pre-pressure gives a higher volume of the expansion vessel. Thus the pre-pressure should be chosen as low as possible. The lowest pressure allowed, is the vertical distance from boiler to the highest system point.

The minimum safety valve opening pressure can be obtained by calculating the saturated water vapor pressure at the system boiling temperature.

<table>
<thead>
<tr>
<th>Temp. /°C</th>
<th>Expansion /%</th>
<th>Temp. /°C</th>
<th>Expansion /%</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0.786</td>
<td>130</td>
<td>7.00</td>
</tr>
<tr>
<td>50</td>
<td>1.21</td>
<td>140</td>
<td>8.00</td>
</tr>
<tr>
<td>60</td>
<td>1.71</td>
<td>150</td>
<td>9.10</td>
</tr>
<tr>
<td>70</td>
<td>2.27</td>
<td>160</td>
<td>10.2</td>
</tr>
<tr>
<td>80</td>
<td>2.90</td>
<td>170</td>
<td>11.4</td>
</tr>
<tr>
<td>90</td>
<td>3.63</td>
<td>180</td>
<td>12.8</td>
</tr>
<tr>
<td>100</td>
<td>4.34</td>
<td>190</td>
<td>14.2</td>
</tr>
<tr>
<td>110</td>
<td>5.20</td>
<td>200</td>
<td>15.7</td>
</tr>
<tr>
<td>120</td>
<td>6.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Percentage expansion of water at different temperatures, relative to volume at 4 °C

8 Ductwork

8.1 Introduction

The purpose of AC/MV duct systems is to convey air to and from spaces within buildings, and provide building occupants with:

- ventilation air
- thermal comfort
- humidity control

The aim of this section is to provide a source of information on current practice in the design of ductwork for ventilation and air conditioning systems. The information is intended to provide an overview of design criteria and application requirements.
The designer must balance the need to minimise energy use and noise generation against space availability and the costs of materials and installation, whilst providing adequate means of access for installation, cleaning and maintenance. Materials, equipment and construction methods should be chosen with respect to the whole life cycle cost of the installation. This is particularly important for new installations for which the Energy Efficiency Building Code sets down strict requirements for maximum fan power.

8.2 Cost efficient ductwork

Significant energy savings can be achieved by reducing unnecessary pressure drops in the system by careful sizing, routing and detailing of ductwork. In particular, pinch points in index runs require higher pressure drops than much of the rest of the system.

Variable flow control of air systems, can give considerable savings in fan energy. Variable flow control vav-systems have potentially greater air distribution savings over other central plant systems, provided that pressures are well controlled and air handling plant and drives are intrinsically efficient.

Variable speed drives also allow rapid matching of fan duties during commissioning and will provide significant savings compared with manual regulation dampers. Typical energy savings are 20% at 90% flow and 40% at 80% flow, dependent upon characteristics. Damper control increases system resistance and therefore energy savings are reduced.

Energy can be reduced in ventilation systems by:
- avoiding unnecessary bends
- using bends instead of elbows
- having a 'shoe' on the branch fittings for tees
- avoiding reduced duct size (i.e. maintain cross sectional area)
- minimising duct length
- minimising the length of flexible ducting
- good inlet and outlet conditions either side of fan
- using equipment with low pressure drops (i.e. filters, attenuators, heat exchangers).

Furthermore lower first costs can be achieved by:
- using the minimum number of fittings possible;
- ensuring ductwork is sealed to minimise air leakage;
- using round ductwork where space and initial costs allow because it offers the lowest duct friction loss for a given perimeter, or given velocity
- when using rectangular ductwork, maintain the aspect ratio as close as possible to 1:1 to minimize duct friction losses and initial cost;

Ductwork should have as large a cross-sectional area as possible to produce low velocity systems and reduce system pressure drops. Figure 6 illustrates the running and capital costs for systems having different design air velocities. These figures show how the running costs are reduced for low velocity systems, and how some components become more expensive while others become cheaper. The benefits of the energy efficient (i.e. low
velocity) system include a reduction in electricity costs of approximately 70%, while the additional capital cost is recovered in less than five years.

The basis of the comparison is as follows:

- all systems supplying 2 m$^3$/s of air
- fan operating at an efficiency of 70%
- pulley and motor efficiencies of 90% and 80%
- electricity cost: 5 pence per kWh
- annual run time: 3000 hours
- noise levels less than 40 dBA.

Energy efficient duct design is characterized by:

- In a low velocity system, the air handling unit face velocity would typically be less than 2 m/s with the main duct velocity less than 3 m/s.
- In a medium velocity system these figures would become 2–3 m/s and 5 m/s.
- In a high velocity system the air handling unit velocity would
typically be greater than 3 m/s with the main duct velocity at 8 m/s.
• Air leakage from ductwork should be minimised to prevent the wastage of fan power.
• Ductwork should be insulated accordingly and runs through unoccupied spaces should be minimised.
• Testing of ductwork air tightness should be undertaken.

Good duct design should achieve airflow that is as laminar as possible throughout the ductwork run to reduce the pressure drop. This can be achieved by:
• Minimizing changing to the direction of the flow
• Radius bends should be used in preference to right angled bends
• Y-junctions should be used in preference to T-junctions
• Turning vanes should be used wherever appropriate

• For rectangular ductwork, the aspect ratio should be as close to unity as possible.

### 8.3. Ductwork classifications

#### 8.3.1 Low, medium and high pressure systems

Ductwork systems for ventilating and air conditioning applications can be divided into low, medium and high pressure systems.

High pressure systems permit smaller ductwork but result in greater friction pressure drop, requiring the fan to generate higher pressures and noise generation. They are more expensive to install and, because of their greater input power requirements, are more expensive to run. Table 5 sets out the classification of ductwork systems.

<table>
<thead>
<tr>
<th>System classification</th>
<th>Design static pressure / Pa</th>
<th>Maximum air velocity / m·s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low pressure (Class A)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Medium pressure (Class B)</td>
<td>1000</td>
<td>750</td>
</tr>
<tr>
<td>High pressure (Class C)</td>
<td>2000</td>
<td>750</td>
</tr>
</tbody>
</table>

*where \( p \) is the static gauge pressure in the duct (Pa)*

Table 5. Maximum pressures and velocities for low, medium and high pressure ductwork.

#### 8.3.2 Ductwork sections

Ducting is generally available in rectangular, circular and flat oval sections, although other sections may be made for special situations.

Recommended sizes for rectangular, circular and flat oval ductwork are given in Appendix 2.

Rectangular ducting
Ductwork less than 0.0225 m² cross sectional area (e.g. 150 mm × 150 mm) will generally be more economic if made from circular section. Rectangular ducting is most common for low pressure systems.
For overall economy and performance, the aspect ratio should be close to 1:1 since high aspect ratios increase the pressure loss, the heat gains/losses and the overall costs. However, ducts with a 1:1 aspect ratio require a deep service area and are therefore rarely used in ceiling zones due to space limitations.

Rectangular ducting should not be the first choice for high pressure systems as it requires strengthening of the flat sides and needs to be sealed to make it suitable for this application.

**Circular ducting**  
Machine formed, spirally wound ducting and a standard range of pressed and fabricated fittings makes circular ducting more economical, particularly in low pressure systems having a relatively small proportion of fittings. It is likely to be easier to install, particularly for the main runs of ductwork.

Circular ducting is preferable for high pressure systems and for systems operating at high negative pressures, due to its high inherent stiffness. Additional stiffening rings may be necessary at high negative pressure.

**Flat oval ducting**  
Flat oval ducting provides an alternative to circular ducting principally where there is a limitation on one of the dimensions in the space available for the duct run. It combines the advantages of circular and rectangular ductwork because it can fit in spaces where there is insufficient room for circular ducting and can be joined using the techniques for circular duct assembly.

**Flexible ductwork**  
The use of flexible ductwork for making final connections to supply diffusers is very convenient. However such ductwork produces pressure drops much greater than those for the equivalent smooth galvanised steel ductwork.

Flexible ductwork naturally has an equivalent roughness which is appreciably more than for galvanised steel ductwork. This alone causes a much greater pressure drop. If the flexible duct is not fully extended then, if the length is only 70% of the extended length, the pressure loss can be greater by a factor of 4.
Thus, when using flexible ductwork, it is recommended that:
• lengths should be kept as short as possible
• it should be almost fully extended.

8.4 Duct work design and sizing

8.4.1 Duct sizing criteria

The criteria to be used when designing a ductwork installation include:
• system pressure
• velocity
• noise levels
• energy consumption
• ductwork distribution
• terminal devices
• capital cost
• operating, maintenance, cleaning and replacement costs.

The smaller the duct sizes, the greater the fan power required and hence the higher the energy consumption. Increasing the duct size can have a large effect on decreasing fan power since the smaller friction drops of the basic circuit will require smaller friction drops through control dampers for the same value of control authority, thus leading to a further saving.

The optimum size from the point of view of life cycle costing must consider the length of the system, the capital cost, the mean pressure drop, the running time at full and partial load, the efficiency of the fan and motor combination, anticipated electrical tariffs and costs of cleaning and maintenance of the ductwork system.

Larger ductwork requires more space and has a greater first cost, but it has the advantage of lower noise generation and, more importantly, a lower pressure drop. This result in lower fan power and energy costs.

The Energy Efficiency Building Code now introduces a limiting value of ‘specific fan power’, i.e. the electrical fan power per unit volume flow (W/\text{l}^3/s). Even where this new criterion does not result in larger duct sizes, any duct run requiring damper control should require special consideration.

The basic equations for calculating pressure losses in ductwork and ductwork fittings, along with pressure loss factors, are given in chapter 4.2. Relevant figures and tables can be found in fundamental literature, product brochures etc.

In a complex ductwork system, the duct sizes should be chosen in such a way that each circuit is inherently balanced. Where there is a mixture of short and long branches, the long runs should have larger ducts in order to reduce their resistance. Better still is a design where the branches are all of approximately the same length.

Even for a small system, the fan pressure rise required must be equal the system pressure drop for the whole air circuit.

For a supply-only system or an extract system, the total pressure drop of the system must include the pressure drop through the extract grille or inward/outward leakage routes.

However the designer should not feel constrained by any of them. The final design constraints to be satisfied are:

• compliance with legislation (energy, fire/safety)
• no objectionable noise generation
• no excessive pressure drop
• all air routes (circuits) to be in balance at the design stage.

The architect may wish to add another, namely that the size be minimised, but this might be incompatible with the above constraints.

8.4.2 Air flow in ducts
In normal circumstances the flow of air in ducts is turbulent with the flow generally in the direction of the duct axis. Eddies and secondary motions will result in energy dissipation due to internal fluid friction, and streamlines will not be parallel to the duct centre-line.

In duct design the important aspects of the effects of disturbance to airflow are:
• increased pressure loss due to creation of eddies
• increased pressure loss as high velocity air mixes with low velocity air
• noise generated by the interaction on eddies with the inner surfaces of the ducts.

Optimum design of turning vanes, with careful positioning, should provide a bend with less resistance to airflow than a good design of radiused bend, but this may not be achieved in practice. This is because the inside and outside corners of the bend are usually not rounded and internal and side fixings provide some obstructions. The pressure losses may then be a little higher than those in a good design of radiused bend, particularly in the case of small duct sizes.

8.4.3 Ductwork sizing process
Duct sizing is an iterative process following identification of the duct runs. It requires determining the air flow requirements in the main ducts and subsidiary branches to assess the size of each. These then need to be checked against the original design parameters. A balance needs to be obtained between the duct sizes required to achieve the design outputs and the space allocated for the ductwork system.

Materials, equipment, fittings and construction methods need to be chosen with respect to whole life costs, not just the initial or installation cost. It can be beneficial and cost effective to standardise the types and sizes of the ducts and fittings used in the installation.

The areas served by the risers are likely to dictate the size of the horizontal
branches. The depth of horizontal ductwork will also have a significant influence on the depth of false ceilings or floors and the overall floor-to-floor height.

8.4.4 Design principles

Duct sizing and pressure loss calculations are normally carried out as a combined exercise to quantify the ductwork dimensions and provide data for specifying the fan duty. The duct sizing process and pressure loss calculations require the specification of system requirements, including:

- system type, i.e. low, medium, high pressure or industrial
- volume flow rates in all parts of the ductwork
- positions of fans, other plant items, supply and extract terminals
- special operating requirements,
- ductwork type, i.e. circular, rectangular, flat oval
- layout of the duct runs, including fittings, dampers and plant items
- duct material.

The purpose of duct sizing is to determine the cross sectional dimensions of the various parts of the duct system, taking into account that the system, fans and other plant items should:

- have low initial and operating costs
- be compatible with the space limitations imposed by the structure and other services
- be sufficiently quiet in operation
- be easily regulated after installation to achieve the design airflow at each terminal.

8.4.5 Manual duct sizing method

A simple duct design based on constant pressure drop with maximum duct velocities as set out in Table 6 is appropriate for low, medium and high pressure systems. It is recommended that size is rounded to the nearest recommended duct size before the system resistance calculation is carried out. The method is a simple procedure...
which use ductwork data charts to determine duct dimensions.

A brief description of the method is given below.

Typical air velocities and maximum pressure drops are given in Table 7-11. The pressure drop at diffuser ends should not exceed 20-30 Pa due to unnecessarily energy consumption.

### Table 6. Typical air velocities for ductwork

<table>
<thead>
<tr>
<th>System type</th>
<th>Velocity / m·s⁻¹</th>
<th>Maximum pressure drop per unit length / Pa·m⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low velocity</td>
<td>3–6</td>
<td>1</td>
</tr>
<tr>
<td>High velocity</td>
<td>7.5–15</td>
<td>8</td>
</tr>
</tbody>
</table>

### Table 7. Typical air velocities for air handling units and other components

<table>
<thead>
<tr>
<th>Situation</th>
<th>Velocity / m·s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating system</td>
<td>2.5–4 (through face area)</td>
</tr>
<tr>
<td>Cooling system</td>
<td>1.5–2.5 (through face area)</td>
</tr>
<tr>
<td>Inlet louvres</td>
<td>2.5 (through face area)</td>
</tr>
<tr>
<td>Extract louvres</td>
<td>2.5 (through face area)</td>
</tr>
<tr>
<td>Filters</td>
<td></td>
</tr>
<tr>
<td>- flat panel</td>
<td>As duct</td>
</tr>
<tr>
<td>- pleated</td>
<td>&lt; 3.8</td>
</tr>
<tr>
<td>- HEPA</td>
<td>1.3</td>
</tr>
<tr>
<td>- moving curtain</td>
<td>2.5</td>
</tr>
<tr>
<td>- viscous</td>
<td></td>
</tr>
<tr>
<td>- moving curtain</td>
<td>1.0</td>
</tr>
<tr>
<td>- dry</td>
<td></td>
</tr>
<tr>
<td>- electronic, ionising</td>
<td>0.8–1.8</td>
</tr>
</tbody>
</table>

### Table 8. Recommended maximum duct velocities for low pressure ductwork system related to noise generation.

<table>
<thead>
<tr>
<th>Typical applications</th>
<th>Typical noise rating (NNL)</th>
<th>Velocity / m·s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Main duct</td>
</tr>
<tr>
<td>Domestic buildings</td>
<td>25</td>
<td>5.0</td>
</tr>
<tr>
<td>Theatres, concert halls</td>
<td>20–25</td>
<td>4.0</td>
</tr>
<tr>
<td>Auditoria, lecture halls, cinemas</td>
<td>25–30</td>
<td>4.0</td>
</tr>
<tr>
<td>Bedrooms (non-domestic buildings)</td>
<td>20–30</td>
<td>5.0</td>
</tr>
<tr>
<td>Private offices, libraries</td>
<td>30–35</td>
<td>6.0</td>
</tr>
<tr>
<td>General offices, restaurants, banks</td>
<td>35–411</td>
<td>7.5</td>
</tr>
<tr>
<td>Department stores, supermarkets, shops, cafeterias</td>
<td>40–45</td>
<td>9.0</td>
</tr>
<tr>
<td>Industrial buildings</td>
<td>45–55</td>
<td>13.0</td>
</tr>
</tbody>
</table>
Constant pressure drop (equal friction loss) method.

The basis for this method is to select a constant pressure loss per unit length for the duct runs and then to size the ducts at this rate, using Figure 7.

The method is used for the sizing simple low pressure supply and extract systems, some medium pressure systems and also for variable air volume (VAV) systems. For low pressure systems, typical values used for the constant pressure loss rate are in the range 0.8–1.2 Pa/m with duct velocities not exceeding 10 m/s. At large volume flow rates in low pressure systems the 10 m/s duct velocity limit should override the constant pressure loss rate chosen, leading to somewhat lower pressure loss rates in the large ducts.

The sizing process involves:

(a) The selection and use of a vertical constant pressure loss line on Figure 12, appropriate to the design requirement
(b) reading-off the circular duct diameter for the actual volume flow rate
(c) if a rectangular or flat oval duct is required, taking the dimensions from Tables in Appendix 2.

Example:
In this example the system type is low velocity whereas the pressure drop per meter will be 1 Pa. There is at required flow of 4000 m³/h (=1.11 m³/s). In figure 12 the diameter can be obtained. There’s no exact match for the criteria’s, thus a diameter of 0.45 m is selected and the actual pressure loss can be established (1.4 Pa/m) by following the flow line (see figure 12). If a rectangular duct for some reason should be wanted appendix 2 provide tables for conversion. In this case a rectangular duct could be 500x400.

The chart is an example valid only for air in circular galvanized ducts.
Figure 12. Pressure drop for air in galvanized circular ducts (ρ 1.2 kg/m³, T = 283 K)

The pressure loss method gives a reducing velocity from the fan to the terminals but does not ensure that the branch flow rates are inherently balanced. Provision for site regulation needs to be included in the design. Adopting different pressure loss rates for the individual branches of a system can be used to
produce a more nearly equal resistance to each duct run and so assist site commissioning. This modification can be introduced during the pressure loss calculation.

Initially, all parts of the system should be sized to the same pressure loss rate and the adjustments to individual branch sizes only carried out after the pressure losses in the initial system design have been computed. These adjustments are most quickly and conveniently carried out by computer.

8.4.6 Total system pressure loss

The pressure loss in a ductwork system is made up of the pressure losses at plant items and terminal equipment, the friction loss in the straight ducts plus the losses due to duct fittings.

The losses due to both straight duct and fittings are directly related to the duct sizes, so that the determination of the system pressure loss follows the duct sizing process.

The total pressure loss of plant items and fittings is related to the static pressure loss as follows:

\[ \Delta pt = \Delta p + pvi - pvo \] (8.1)

Where:

- \( \Delta pt \) is the total pressure loss (Pa),
- \( \Delta p \) is the static pressure loss (Pa),
- \( pvi \) is the inlet velocity pressure (Pa),
- \( pvo \) is the outlet velocity pressure (Pa).

In the case of plant items and fittings where the inlet and outlet connection areas and flow rates are equal, then \( pvi = pvo \) and the total and static pressures are identical.

The advantage of using total pressure losses is that the friction and fitting losses are such that the total pressure always decreases in the direction of airflow so that the losses can simply be added.

The total pressure loss of the terminals must be included in the overall total system pressure loss.

The required fan total pressure for the system is equal to the system pressure loss but it is prudent to allow a margin on the calculated total pressure loss.

The first step in the manual calculation of the total pressure loss in a system is to identify the 'index' duct run. This is the duct run that has the greatest total pressure loss. Normally the index run will be that which links the fan and the most distant terminal. However, this is not automatically true because it is possible for shorter runs to have higher pressure losses if they contain plant items, high pressure loss terminals or a high proportion of duct fittings.

The second step is to compute the index run total pressure loss. This calculation should (for a supply system) typically include pressure losses at the following items:

- **entry**: intake opening, louvres, bird screens
- **suction duct**: straight duct sections, duct fittings,
- **control and fire dampers**, mixing chambers
- **plant**: filters (dirty condition), heaters, cooling coils, humidifiers, eliminators, attenuators
- **fan**: inlet vanes, inlet duct connection, outlet duct
- **connection**, flexible connections
- **supply duct**: straight duct sections, attenuators, duct
- fittings, balancing and fire dampers, zone plant
- items, control boxes, flexible ducting, terminals.

Where the connections to equipment are different in size, or where multiple connections occur, the manufacturer’s pressure loss data should be checked to ensure that they are the total pressure losses.

A large number of bends, expansion and contraction results in increased pressure loss and turbulence in the duct system, and consequently increased electricity consumption for operation of the fan. The tables below shows some pressure loss figures.

**Round bends**
In low pressure systems bend radius should be greater or equal to the diameter. In medium and high pressure systems Radius / diameter ratio R / D should be at least 2. The table shows the relationship between the radius / diameter ratio R / D and pressure loss factor, \( \zeta \).

<table>
<thead>
<tr>
<th>R/D</th>
<th>( \zeta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,0</td>
<td>0,33</td>
</tr>
<tr>
<td>1,5</td>
<td>0,24</td>
</tr>
<tr>
<td>2,0</td>
<td>0,19</td>
</tr>
<tr>
<td>3,0</td>
<td>0,17</td>
</tr>
</tbody>
</table>

**Rectangular bends - elbows**
In sharp edged rectangular bends should be inserted vanes. The table shows pressure loss factor, \( \zeta \) for rectangular bends with and without vanes.

<table>
<thead>
<tr>
<th>Type</th>
<th>( \zeta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>With vanes</td>
<td>1,4</td>
</tr>
<tr>
<td>Without vanes</td>
<td>0,35</td>
</tr>
</tbody>
</table>

**Changing the channel cross section.**

The table shows pressure loss factor, \( \zeta \) of the cross-sectional changes.

<table>
<thead>
<tr>
<th>Type</th>
<th>( Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>No transition fitting</td>
<td>0,56</td>
</tr>
<tr>
<td>With transition fitting</td>
<td>0,33</td>
</tr>
</tbody>
</table>

**Branches**
In systems with air velocity greater that 3 m/s T-junction should be avoided. Branches with 15\(^\circ\), 30\(^\circ\) or 45\(^\circ\) angels should be preferred.

<table>
<thead>
<tr>
<th>Type</th>
<th>( Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-branch</td>
<td>0,51</td>
</tr>
<tr>
<td>15(^\circ) branch</td>
<td>0,02</td>
</tr>
</tbody>
</table>

**8.5 Space allowance for ductwork**

Provision of sufficient space for ductwork is essential and must be addressed at an early stage in the design process of the building. Adequate space must be provided for installation and maintenance of the ductwork and associated equipment. The designer should ensure that ductwork is accommodated in the same space, particularly in false ceiling voids and riser spaces where there may be several distribution systems vying for restricted space.

The depth selected for a branch duct will have a significant influence on the false ceiling or raised floor depth. It will also affect the overall floor-to-floor...
heights and hence have significant influence on building costs.

Figure 8 shows the recommended allowances for typical ductwork.

Consideration should also be given to how the ductwork will be tested and, eventually, replaced, as access to fire dampers must not be obstructed by other services. Clear access must be ensured for inspection and testing.

Annex 3 shows typical floor-to-floor heights and the heights/depths of typical false floors/ceilings.

8.6 Duct and Diffuser Location

Ducts in conditioned space are the most energy-efficient duct location. Heat gains and losses are minimized and go directly to the conditioned space.

Ducts in unconditioned space are located outside the building thermal barrier, such as attics, basements or covered parking areas. Attics are often hotter than outdoors, resulting in high conductive heat transfer through the ductwork and leakage of unconditioned air into the HVAC system. When ducts are located in an attic, locate them underneath insulation whenever possible.

Building cavities used as ducts, such as enclosed support platforms, mechanical rooms, ceiling spaces, wall and cavities and chases, are usually less airtight than standard ducts and plenums.

Ducts outside the building incur the greatest thermal losses and energy penalties, especially when exposed to solar gain. Factors affecting losses include air leakage, heat conduction, solar radiation, and solar reflection effects.

Duct location recommendations
1. Locate ductwork within conditioned space whenever possible.
2. Plan locations to minimize duct lengths, turns and fittings.
3. Avoid locating ductwork in exterior walls where the ductwork may displace wall insulation.
4. With the exception of ceiling return plenums and under-floor air delivery, building cavities should not be used for air distribution. Enclosed airhandler support platforms are one of the largest source of leaks in a system.
5. When chases, furred spaces or other cavities (except ceiling return plenums) are used for air pathways, provide sealed ductwork within the cavity to convey the air.
6. Ceiling spaces should only be used as return-air plenums when the thermal insulation is located above the plenum.
7. Ducts in unconditioned spaces and outside the building should be well insulated. Locate away from sources of heat and in shaded areas when possible.
8. Unconditioned attic spaces containing ducts should be well ventilated.
9. Ducts in false ceilings should be well insulated to minimize energy loss hence the temperature in the false ceiling could be significantly higher than the room temperature.

**Diffusers location recommendations**

Diffusers should be positioned in respect of length of throw and shorting. These values depend on the data from the manufacture of the diffuser and the layout of the ductwork. It’s important not to place the inlet and the outlet too close to each other whereas the inlet air will be sucked out immediately after entering the room.

The main air intake and outlet must be carefully located to avoid drawing in external pollutants and must not be obstructed or blocked. Furthermore the intake should be located in the shade and in a way that intake air will not be contaminated by the outlet air.

**8.7 Air Leakage**

It is recommended as good practice that all significant installations (e.g. those with a fan capacity greater than 1 m$^3$/s) should be tested in accordance with an approved testing method.

Leakage from ducted air distribution systems is an important consideration in the design and operation of ventilation and air conditioning systems. A ductwork with a minimum of air leakage will also ensure that energy and operational costs are not greater than necessary.

The effect of air leakage from high pressure ductwork is critical in terms of system performance, energy consumption and the risk of high frequency noise associated with leakage. These problems are less critical with medium pressure systems, but should be considered. Low pressure ducts present the lowest risk in terms of the effect of leakage on the effective operation of the system.

Items of equipment and plant installed in ductwork systems can also leak and particular attention should be paid to the sealing of these items. Where leakage testing is required, the designer should ensure that suppliers of these items can demonstrate that their equipment meets the required air tightness standards.

The designer should make adequate allowance in the fan selection for some air leakage so that the completed installation can meet its intended purpose without subsequent adjustments to the fan(s) and motor(s).

It is generally accepted that, in typical good quality systems, the leakage from each category of duct under operating conditions will be in the region of:

— low pressure: 6%
— medium pressure: 3%
— high pressure: 2%

**8.8 Condensation in ductworks**

Condensation of water vapour within air occurs whenever the temperature falls below the ambient dew-point. This can occur on the outside of the cold duct or diffuser when the temperature of the duct air causes the duct itself to have a temperature below the dew-point of the surrounding air.

At the diffuser end, the inlet air temperature should be above the dew-point to avoid condensation.

Condensation can lead to corrosion of the ductwork as well as diminishing the thermal resistance of the insulation, and
consequently increase in energy consumption for cooling.

Vapour sealing will be required where the temperature of the air within the duct is at any time low enough to promote condensation on the exterior surface of the duct and cause moisture penetration through the thermal insulation. The vapour barrier must be carefully installed to ensure the seal is continuous with no routes for penetration of humidity.

With a suitable choice of insulation material and thickness, the surface temperature of the ductwork can be raised sufficiently above the ambient dew point temperature to avoid surface condensation on the duct.

Thermal insulation with a low value of permeability is recommended. Polystyrene foam provides a high resistance to vapour transfer, other thermal insulation materials, e.g. rockwool, have minimal vapour resistance.

8.9 Health and safety
Health considerations will be addressed if a good inspection, maintenance and cleaning regime is applied. Two aspects of safety concerning ductwork need to be addressed:

- **During design**: that there are safe and secure means of access to the ductwork and associated plant and equipment (e.g. filter housings) for inspection, maintenance and cleaning
- **During installation**: by ensuring that the ductwork can be installed safely and securely.

In order to maintain ductwork hygiene, both the supply and recirculated air streams should be clean. Access must be available for cleaning to minimise the build up of microbial growth on duct work, fan blades or coils. The latter can result in loss of performance.

8.10 Fire issue
Fire and smoke containment/hazards are factors which influence the design and installation of duct work systems.

The Fire Safety Requirement Guidelines issued under Local Government Act 2003 Section 98(3) provided in article 4.9.6 Ventilation defines:

“Any system of ventilation shall be designed so that in case of a fire the air movement in the building is directed away from protected escape routes and exits; or that the system is closed down.

Where a pressurisation system is installed, ventilation and air conditioning systems in the building shall be compatible with it when operating under fire conditions”

And in article 5.7, Permitted openings in compartment walls and floors:

“1. Any compartment wall or compartment floor shall be imperforate except for any one or more of the following:

(v) An opening for a chimney, ventilation duct or duct encasing one or more flues or a refuse duct where a construction is made of non combustible material with a period of fire resistance equal to that of the compartment wall or compartment floor and the space surrounding the chimney or duct is fire stopped”

The potential for ducting to spread fire or smoke through a building must therefore be considered at an early stage of the design. And it is recommended that the design is discussed with the Local Authority at the earliest opportunity, and
the system meet requirements set in guidelines issued.

8.10.1 Fire protection of ducts

Protection using fire dampers
The fire is isolated in the compartment of origin by the automatic or manual actuation of closures within the system. Fire dampers should, therefore, be sited at the point of penetration of a compartment wall or floor, or at the point of penetration of the enclosure of a protected escape route. Fire dampers should be framed in such a way as to allow for thermal expansion in the event of fire, and the design must provide for the protection of any packing material included.

![Figure 9. Fire damper for wall or floor installation.](image)

Protection using fire resisting enclosures
Where a building services shaft is provided through which the ventilation ductwork passes, and if the shaft is constructed to the highest standard of fire resistance of the structure which it penetrates, it forms a compartment known as a ‘protected shaft’. This allows a complicated multiplicity of services to be transferred together through a shaft transversing a number of compartments and reaching remote parts of the building, without requiring further internal divisions along its length. The provision of fire dampers is then required only at points where the ventilation duct leaves the confines of the protected shaft.

Protection using fire resisting ductwork

In this method of fire protection, the ductwork itself forms a protected shaft. The fire resistance may be achieved by the ductwork material itself, or through the application of a protective material. Where the fire resisting ductwork passes through a fire compartment wall or floor, a penetration seal must be provided which has been tested and/or assessed with the ductwork to, to the same fire rating as the compartment wall through which the fire resisting ductwork passes.

8.11 Flow regulation

One of the basic requirements for an effective system is having the necessary dampers in the correct position. Recommended siting for dampers:

- Main damper for the air handling unit,
- On all terminals and in all branch and sub-branch ducts.
- In connecting ducts to terminals
- As flow measurements and adjustments

Annex 4 shows recommended damper positions.

8.12 Noise generation in ducts

Noise in ductwork can be contentious, particularly where the system or components (e.g. intake, exhaust, air handling unit etc.) produce a noise nuisance to the building occupants, neighbours etc. Noise is generated where eddies are formed as flow separates from a surface. The generated noise level is particularly sensitive to the velocity.

Noise should be prevented from getting through to the occupied spaces. Design features in support of this objective, which largely correspond to those required for energy efficiency, include the following:

- Low air velocity in the ductwork
• The use of round ducts
• The use of bends with large internal radii
• Smooth transitions and changes in flow direction
• The use of low-noise control vanes
• Low air leakage.

This noise, also known as regenerated noise, is produced by turbulence in the airflow. It is reduced by ensuring streamline flow and minimising obstructions or abrupt changes in the flow. Airflow noise increases as approximately the sixth power of flow velocity and is generally broad band. Reduction of velocity is achieved by increasing the duct size or, for example, running two parallel ducts. Where it is anticipated that velocity generated noise will be a problem, silencing must be installed after the final in-duct noise source. For typical fittings and flow velocities, the overall regenerated power level is likely to be in the region of 50–70 dB.

Figure 10. Illustrates good principles of duct design in order to avoid turbulence, pressure loss and noise.

Dampers should be fitted at least 1.5 to 2.0 meters back from a duct termination in order to reduce damper noise escaping into occupied space.

Damper manufacturers can supply information from which the regenerated noise of their products may be estimated. The information is often provided in terms of air velocity, resulting pressure drop and a reference overall regenerated sound power level.

The aim should be for system design and construction which ensures that regenerated noise in the duct is not a problem.
8.12.1 Silencers
Silencers are an obstruction in the flow and therefore generate turbulence noise. This noise, which is dependent on flow velocity, is sometimes referred to as the ‘self-noise sound power level’ of the silencer. Self-noise is likely to be from 50 to 80 dB overall sound power level. Manufacturers’ data must be consulted.

8.12.2 Passive silencers
A passive silencer contains of sound absorbent, normally associated with narrowed air passages. Both rectangular and circular silencers are used.

The rectangular silencer is built up from an assembly of absorbent splitter modules. The parallel assemblies give increased capacity to carry the required air volume without increase of velocity. The cross section of the silencer is often significantly greater than that of the duct in which it is located.

Another important variable is the length of the silencer. Silencer pressure loss is not proportional to the length of the silencer, since significant pressure loss occurs at the entry and exit. A circular silencer is normally either open (‘unpadded’) or contains an inner assembly, the absorbent ‘pod’ or ‘bullet’.

Factors to be considered in selecting a silencer include its attenuation at different frequencies and its pressure loss. Duct designs leading to poor entry and exit flow conditions increase the pressure loss and may generate additional low frequency noise.

Particular attention should be given to the exit conditions. It is advisable to locate silencers several duct widths or diameters clear of bends, in order to maintain good airflow.

Location of a silencer should be between the major noise source and the occupied space, preferably between straight duct runs in order to give good flow conditions at the entrance and exit to the silencer.

Often the major noise source is the plant room fan, but fan coil units, for example, introduce noise sources closer to the occupied space. A length of lined duct, between a ceiling space fan coil and the duct termination, may be adequate to deal with fan coils.
Appendices

Appendix 1 Recommended minimum thickness for insulation

<table>
<thead>
<tr>
<th>Minimum air temp. inside duct / °C</th>
<th>Minimum thickness of insulating material (mm) for stated thermal conductivity $\lambda$ (W/m·K) and external surface emissivity $\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda = 0.02$</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon = 0.05$ $\varepsilon = 0.44$ $\varepsilon = 0.9$</td>
<td>$15$</td>
</tr>
<tr>
<td>$10$</td>
<td>$20$</td>
</tr>
<tr>
<td>$5$</td>
<td>$37$</td>
</tr>
<tr>
<td>$0$</td>
<td>$48$</td>
</tr>
<tr>
<td>$\lambda = 0.025$</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon = 0.05$ $\varepsilon = 0.44$ $\varepsilon = 0.9$</td>
<td>$15$</td>
</tr>
<tr>
<td>$10$</td>
<td>$20$</td>
</tr>
<tr>
<td>$5$</td>
<td>$37$</td>
</tr>
<tr>
<td>$0$</td>
<td>$48$</td>
</tr>
<tr>
<td>$\lambda = 0.03$</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon = 0.05$ $\varepsilon = 0.44$ $\varepsilon = 0.9$</td>
<td>$15$</td>
</tr>
<tr>
<td>$10$</td>
<td>$20$</td>
</tr>
<tr>
<td>$5$</td>
<td>$37$</td>
</tr>
<tr>
<td>$0$</td>
<td>$48$</td>
</tr>
<tr>
<td>$\lambda = 0.035$</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon = 0.05$ $\varepsilon = 0.44$ $\varepsilon = 0.9$</td>
<td>$15$</td>
</tr>
<tr>
<td>$10$</td>
<td>$20$</td>
</tr>
<tr>
<td>$5$</td>
<td>$37$</td>
</tr>
<tr>
<td>$0$</td>
<td>$48$</td>
</tr>
</tbody>
</table>

Note: (a) Assumes ambient conditions of 25°C still air, 80% relative humidity, dewpoint temperature 21.3°C. (b) Thicknesses calculated in accordance with BS EN ISO 12241.[10] Based on 0.6 m vertical flat surface of rectangular duct but are also adequate for horizontal surfaces. (c) Thermal conductivity values of insulating materials quoted at mean temperature of 10°C.

Recommended minimum thickness of insulation on ductwork carrying chilled air

<table>
<thead>
<tr>
<th>Temperature difference between air inside duct and ambient / K</th>
<th>Environmental thickness of insulating material (mm) for stated thermal conductivity $\lambda$ (W/m·K)</th>
<th>Corresponding heat loss / W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10$</td>
<td>$\lambda = 0.02$</td>
<td>$19$</td>
</tr>
<tr>
<td>$25$</td>
<td>$\lambda = 0.03$</td>
<td>$25$</td>
</tr>
<tr>
<td>$50$</td>
<td>$\lambda = 0.04$</td>
<td>$32$</td>
</tr>
</tbody>
</table>

Notes: (a) Environmental thicknesses and heat loss values calculated in accordance with BS EN ISO 12241.[10] Based on 0.6 m depth of vertical flat surface of rectangular duct but are also adequate for horizontal surfaces. (b) Heat loss values based on insulation with low emissivity finish ($\varepsilon = 0.5$) in ambient still air at 10°C. (c) For intermediate temperature differences, the insulation thickness can be derived by interpolation. (d) Thermal conductivity values of insulating materials quoted at mean temperature of 10°C.

Recommended minimum thickness of insulation on ductwork carrying warm air
<table>
<thead>
<tr>
<th>Nominal size of Pipe (mm)</th>
<th>28°C, 80% RH</th>
<th>30°C, 95% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>20</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>25</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td>35</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>40</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td>50</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td>55</td>
<td>19</td>
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</tr>
<tr>
<td>80</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>125</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>250</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>300</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>350</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>400</td>
<td>21</td>
<td>33</td>
</tr>
</tbody>
</table>

**Recommended minimum thickness of insulation for indoor chilled water pipes**
<table>
<thead>
<tr>
<th>Nominal size of Pipe (mm)</th>
<th>0.024</th>
<th>0.04</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35°C, 95% RH</td>
<td>35°C, 95% RH</td>
</tr>
<tr>
<td>15</td>
<td>45</td>
<td>32</td>
</tr>
<tr>
<td>20</td>
<td>46</td>
<td>33</td>
</tr>
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<td>25</td>
<td>48</td>
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<td>32</td>
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<td>37</td>
</tr>
<tr>
<td>40</td>
<td>52</td>
<td>38</td>
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<td>50</td>
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<td>73</td>
<td>51</td>
</tr>
<tr>
<td>400</td>
<td>74</td>
<td>52</td>
</tr>
</tbody>
</table>

**Notes:**
1. The above table assumes pipes to be steel pipe of BS1387 or BS3600. For other metal pipes, some insulation thickness is applied to comparable outer diameters.
2. The insulation thickness in above table is based on thermal conductivity rated at 20°C mean for fluid operating temperature of 3°C.
3. The surface coefficient h=9 is assumed for bright metal surfaces and h=13.5 for cement or black matt surfaces at outdoor condition with a wind speed of 1m/s.

*Recommended minimum thickness of insulation for outdoor chilled water pipes*
**Appendix 2 Recommended sizes for ductwork**

**Circular ducting**

<table>
<thead>
<tr>
<th>Diameter, (d)/ mm</th>
<th>Perimeter, (P)/ m</th>
<th>Hydraulic diameter, (d_h)/ mm</th>
<th>Cross sectional area, (A)/ m(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>0.198</td>
<td>63</td>
<td>0.004</td>
</tr>
<tr>
<td>80</td>
<td>0.251</td>
<td>80</td>
<td>0.006</td>
</tr>
<tr>
<td>100</td>
<td>0.314</td>
<td>100</td>
<td>0.010</td>
</tr>
<tr>
<td>125</td>
<td>0.393</td>
<td>125</td>
<td>0.156</td>
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<tr>
<td>150</td>
<td>0.470</td>
<td>150</td>
<td>0.023</td>
</tr>
<tr>
<td>160</td>
<td>0.502</td>
<td>160</td>
<td>0.026</td>
</tr>
<tr>
<td>200</td>
<td>0.628</td>
<td>200</td>
<td>0.040</td>
</tr>
<tr>
<td>250</td>
<td>0.785</td>
<td>250</td>
<td>0.063</td>
</tr>
<tr>
<td>315</td>
<td>0.990</td>
<td>315</td>
<td>0.099</td>
</tr>
<tr>
<td>355</td>
<td>1.115</td>
<td>355</td>
<td>0.126</td>
</tr>
<tr>
<td>400</td>
<td>1.257</td>
<td>400</td>
<td>0.160</td>
</tr>
<tr>
<td>450</td>
<td>1.413</td>
<td>450</td>
<td>0.203</td>
</tr>
<tr>
<td>500</td>
<td>1.571</td>
<td>500</td>
<td>0.250</td>
</tr>
<tr>
<td>560</td>
<td>1.760</td>
<td>560</td>
<td>0.314</td>
</tr>
<tr>
<td>630</td>
<td>1.079</td>
<td>630</td>
<td>0.397</td>
</tr>
<tr>
<td>710</td>
<td>2.229</td>
<td>710</td>
<td>0.504</td>
</tr>
<tr>
<td>800</td>
<td>2.512</td>
<td>800</td>
<td>0.640</td>
</tr>
<tr>
<td>900</td>
<td>2.826</td>
<td>900</td>
<td>0.810</td>
</tr>
<tr>
<td>1000</td>
<td>3.142</td>
<td>1000</td>
<td>1.000</td>
</tr>
<tr>
<td>1120</td>
<td>3.517</td>
<td>1120</td>
<td>1.254</td>
</tr>
<tr>
<td>1250</td>
<td>3.927</td>
<td>1250</td>
<td>1.563</td>
</tr>
</tbody>
</table>

*Points refers to example in section 8.4.5*
Points refers to example in section 8.4.5
Flat oval ducting

<table>
<thead>
<tr>
<th>Perimeter / m</th>
<th>Width of duct (major axis) / mm for stated depth of duct (minor axis) / mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
</tr>
<tr>
<td>0.718</td>
<td>320</td>
</tr>
<tr>
<td>0.798</td>
<td>360</td>
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<tr>
<td>0.878</td>
<td>400</td>
</tr>
<tr>
<td>0.958</td>
<td>440</td>
</tr>
<tr>
<td>1.037</td>
<td>480</td>
</tr>
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<td>1.117</td>
<td>520</td>
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<tr>
<td>1.197</td>
<td>545</td>
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<td>1.277</td>
<td></td>
</tr>
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<td>1.436</td>
<td></td>
</tr>
<tr>
<td>1.596</td>
<td></td>
</tr>
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<td>1.756</td>
<td></td>
</tr>
<tr>
<td>1.915</td>
<td></td>
</tr>
<tr>
<td>2.075</td>
<td></td>
</tr>
<tr>
<td>2.238</td>
<td></td>
</tr>
<tr>
<td>2.394</td>
<td></td>
</tr>
<tr>
<td>2.553</td>
<td></td>
</tr>
<tr>
<td>2.873</td>
<td></td>
</tr>
<tr>
<td>3.192</td>
<td></td>
</tr>
<tr>
<td>3.511</td>
<td></td>
</tr>
<tr>
<td>3.830</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 3 Typical floor-to-floor heights and height/dept hs of typical false floors/ceiling

<table>
<thead>
<tr>
<th>Office type</th>
<th>Typical floor-to-floor height / m</th>
<th>Typical false ceiling height / m</th>
<th>Typical false floor depth* / m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average quality office, refurbished office, average requirements for IT and engineering services</td>
<td>3.0 - 3.8</td>
<td>0.5 - 0.6</td>
<td></td>
</tr>
<tr>
<td>High quality office, minimal perimeter systems; above average requirements for IT and engineering services</td>
<td>3.9 - 4.2</td>
<td>0.8 - 1.0</td>
<td>0.4 - 0.6</td>
</tr>
</tbody>
</table>

* Option to reduce false ceiling height

Appendix 4 Damper positions.
### Appendix 5 Values of equivalent roughness, $k$, for various pipe and duct materials

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Condition</th>
<th>Roughness, $k$ / mm</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seamless copper, brass, lead</td>
<td>Commercially smooth</td>
<td>0.0015–0.0100</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Cast iron</td>
<td>New</td>
<td>0.25–1.00</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Corroded</td>
<td>1.00–1.25</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>With appreciable deposits</td>
<td>2.0–4.0</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Heavily corroded</td>
<td>up to 3.0</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Steel pipe, seamless</td>
<td>New</td>
<td>0.02–0.10</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Old but cleaned</td>
<td>0.04</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Moderately corroded</td>
<td>0.4</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Water pipelines, used</td>
<td>1.2–1.5</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Encrusted</td>
<td>0.8–0.9</td>
<td>Lamont (9)</td>
</tr>
<tr>
<td></td>
<td>Poor condition</td>
<td>&gt; 5.0</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Steel pipe, welded</td>
<td>New</td>
<td>0.04–1.0</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>With small deposits</td>
<td>1.5</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>With appreciable deposits</td>
<td>2.0–4.0</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Poor condition</td>
<td>&gt; 5.0</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Steel pipe, galvanised</td>
<td>Bright galvanisation, new</td>
<td>0.07–0.10</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Ordinary galvanisation</td>
<td>0.10–0.15</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Steel duct, galvanised</td>
<td>Longitudinal seams</td>
<td>0.05–0.10</td>
<td>ASHRAE (9)</td>
</tr>
<tr>
<td></td>
<td>Spiral seams</td>
<td>0.06–0.12</td>
<td>ASHRAE (9)</td>
</tr>
<tr>
<td>Coated steel</td>
<td>Glass enamel</td>
<td>0.001–0.01</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Asphalt</td>
<td>0.012–0.30</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Glass</td>
<td>Fair-faced brickwork</td>
<td>1.5–7.5</td>
<td>Schneider (9)</td>
</tr>
<tr>
<td></td>
<td>Rough</td>
<td>3.5–40</td>
<td>Schneider (9)</td>
</tr>
<tr>
<td>Plaster</td>
<td>New</td>
<td>0.05–0.15</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Concrete pipes</td>
<td>New</td>
<td>0.25–0.34</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Carefully smoothed</td>
<td>0.5</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Brushed, air-placed</td>
<td>2.3</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Non-smoothed, air-placed</td>
<td>5.0–6.0</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td>Polymers:</td>
<td>New</td>
<td>0.0015–0.010*</td>
<td>Schneider (9)</td>
</tr>
<tr>
<td></td>
<td>PVC-U</td>
<td>0.0015–0.010*</td>
<td>Schneider (9)</td>
</tr>
<tr>
<td></td>
<td>poly-butylene (PB)</td>
<td>0.0015–0.010*</td>
<td>Schneider (9)</td>
</tr>
<tr>
<td></td>
<td>poly-ethylene (PE-X)</td>
<td>0.0015–0.010*</td>
<td>Schneider (9)</td>
</tr>
<tr>
<td></td>
<td>ABS</td>
<td>0.007*</td>
<td>Schneider (9)</td>
</tr>
<tr>
<td>Aluminiun</td>
<td>New</td>
<td>0.007*</td>
<td>ASHRAE (9)</td>
</tr>
<tr>
<td>Flexible duct</td>
<td>Fully extended</td>
<td>1.0–4.6</td>
<td>ASHRAE (9)</td>
</tr>
<tr>
<td>Fibrous glass duct</td>
<td>Spray coated</td>
<td>4.5</td>
<td>ASHRAE (9)</td>
</tr>
<tr>
<td>Rock tunnels</td>
<td>Blast-hewed, little jointing</td>
<td>100–140</td>
<td>Idelchik (9)</td>
</tr>
<tr>
<td></td>
<td>Roughly cut, highly uneven surface</td>
<td>500–1500</td>
<td>Idelchik (9)</td>
</tr>
</tbody>
</table>

* No original source has been found for the surface roughness of PVC-U or ABS, their values being generally assumed to be identical to that of PB and PE-X. The values of $k = 0.007$ mm quoted above are merely those used by manufacturers in their calculations of pressure drop. In this range, the surface is so ‘smooth’ that the value chosen has little effect on the pressure drop calculation.
Appendix 6 Friction loss charts

Figure 1: Friction loss for water in commercial steel pipes (ASHRAE Fundamentals, 2005)

Figure 2: Friction loss for water in copper tubing (Types K, L, M) (ASHRAE Fundamentals, 2005)

Figure 3: Friction loss for water in plastic pipes (ASHRAE Fundamentals, 2005)
Literature

Varmeståbi. Nyt Teknisk Forlag. 4.udgave. 2004

Ventilationsståbi. Ingeniøren bøger. 2.udgave. 2001


Flow of fluids in pipes and ducts. CIBSE Guide. 2007


Heating, ventilating, air conditioning and Refrigeration. CIBSE Guide B. 2005


Guidelines for energy efficient HVAC plant. Department pof Building and Housing. New Zealand. 2009


Best Practice Malaysia. Jesper Vauvert. DANCEED Project.

Guidelines on Energy Efficiency of Air Conditioning Installations. Electrical and Mechanical Services Department The Government of The Hong Kong Special Administrative Region.

Lindab Product Brochures