Air Leakage Detection in Various Cross Sectioned Air Ducts and Research on Manufacturing Methods for Airtightness

By

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ABSTRACT

Air ducts and related equipments are important components of climate and ventilation systems in order to distribute clean air, necessary for the occupied space, to whole system and to control thermal comfort. Despite of Turkish standards on air duct are present, studies on energy consumption associated with air leakage are very rare in Turkey, on the contrary to many developed countries. In this study, the subject of preventing energy losses related to the leakage, which causes inefficient working condition, has been investigated. Firstly, air duct system and quality requirements have been explained and the main standards have been analyzed for airtightness of air distribution systems, as well. Secondly, duct system measurements have been conducted by choosing two different approaches. One approach covers leakage calculation of a single duct by using European Standard called Eurovent, whereas the other one divides the system into single sections and uses the Power Law Model for calculation of leakage occurred in each section.

Single duct leakage measurements were made on 300 mm and 1000 mm diameter circular ducts and 300 mm by 250 mm and 1000 mm by 500 mm flanged joint rectangular ducts for positive internal pressures. Test results showed that duct leakage depends on the method of duct fabrication, method of sealing, workmanship and static pressure differential. Furthermore, calculated leakage factors were under the allowable leakage limits in classification “C” for rectangular and circular ducts that were produced by Venco A.Ş. Comparing rectangular to circular ducts both had the same length of seam and surface area; the leakage from circular ducts was less than 80% from rectangular ducts. The air leakage from all test ducts, with the same lock seam type, decreases, whereas the surface area increases.

Branched duct leakage measurements were made on 300 mm and 630 mm diameter circular ducts and 300 mm by 200 mm and 500 mm by 300 mm rectangular ducts and also air distribution system for positive internal pressures. Test results showed that fittings in a system cause sudden changes in static pressure; therefore, duct leakage depends on fitting locations. The leakage rate in Spiro sealed system was less than 5% Trelleborg sealed system.

The leakage measured in this study showed that seam leakage accounts from 14% to 20% of the total in the two rectangular ducts and from 8% to 13% for the round ducts with Pittsburgh and Spiral lock seams. These data show that the joints are the major source of duct leakage. Improvement in duct construction leading to duct systems with less leakage will need to focus on better joints.

Keywords: airtightness duct system, air duct leakage, duct leakage model, ductwork test procedure and methods.

ÖZ

Hava kanalları ve bağlantı parçaları, yaşam alanları için gerekli temiz havanın tüm sisteme dağıtılması ve ısıl konforun sağlanması açısından klima ve havalandırma tesisatlarının önemli bileşenlerindendir. Hava kanal ve bileşenlerinden meydana gelen hava kaçaklarından dolayı oluşan enerji kayıplarına yönelik araştırmalar pek çok gelişmiş ülkede yapılırken ülkemizde, hava kanalları ile ilgili standartlar oluşturulmasına rağmen, mevcut değildir. Bu çalışmada, hava kaçaklarından meydana gelen verimsiz çalışmanın ve enerji kayıplarının önlenmesi konusu araştırılmıştır. Öncelikle, hava kanalı sistemleri incelenmiştir. Sızdırmaz hava dağıtım sistemleri için dünya standartları araştırılmıştır. Daha sonra, kanal sistemlerinden olan sızıntı ölçümü iki farklı metot kullanılarak gerçekleştirilmiştir. Metotların birinde; tek düz bir kanal boyunca olan sızıntı miktarı Avrupa standartlarına göre hesaplanmıştır. Diğer metot da ise kanal sistemi ayrı gruplara bölünmüş ve her bir grup için Power Law Modeli kullanılarak, kanal sızıntı değerleri hesaplanmıştır.

Düz bir kanaldan olan sızıntı ölçümleri, 300 mm ve 1000 mm çapında yuvarlak kanallar ve 300x250 mm ve 1000x500 mm flanşlı tip dikdörtgen kanallar için pozitif basınç altında yapılmıştır. Test sonuçlarına göre, kanaldan olan sızıntı miktarının kanal içi statik basınç farkına, işçilik uygulamasına, kullanılan conta profiline ve kanalın üretim metoduna bağlı olarak değiştiği görülmüştür. Ayrıca, Venco A.Ş. tarafından üretilen dikdörtgen ve yuvarlak hava kanallarından olan sızıntı miktarlarının, C- sınıfı için izin verilen değerlerde olduğu görülmüştür. Eşit yüzey alanına ve kenet uzunluğuna sahip, dikdörtgen ve yuvarlak kanallar karşılaştırıldığında; yuvarlak kanaldan olan sızıntı miktarı, dikdörtgen kanala göre %80 daha azdır.Aynı kenet yapısına sahip, test edilen tüm kanallardan olan sızıntı miktarı, yüzey alanı arttıkça azalmaktadır.

Farklı bölümlerden oluşan kanal sızıntı ölçümleri, 300 mm ve 630 mm çapında yuvarlak kanallar ve 300x200 mm ve 500x300 mm dikdörtgen kanallar ve ayrıca hava dağıtım sistemi için pozitif basınç altında yapılmıştır. Test sonuçlarında, bir sistemdeki bağlantı parçalarının sistemdeki statik basınçta ani değişimlere neden olduğu görülmüştür; bu nedenle, kanaldan olan sızıntı, bağlantı parçalarının bulunduğu yere göre değişmektedir. Spiro conta ile birleştirilmiş kanal sisteminden olan sızıntı miktarı, Trelleborg conta ile karşılaştırıldığında %5 daha azdır.

Bu çalışmada yapılan sızıntı ölçümlerinde; flanşlı ve contalı birleştirilmiş dikdörtgen kanaldan olan toplam sızıntının %14 ile %20'sinin Pittsburgh kenet yapısından kaynaklandığı, ve contalı ve manşonlu birleştirilmiş yuvarlak kanaldan olan toplam sızıntının %8 ile % 13'ünün Spiral kenet yapısından kaynaklandığı görülmüştür. Belirtilen yüzdelik dilimler esas alındığında; hava kanallarından olan sızıntının en önemli kaynağının köşe ve birleşme yüzeylerinin olduğu görülür.

Anahtar Kelimeler: sızdırmaz hava kanalı sistemleri, hava kanalı sızıntısı, kanal sızıntı modeli, hava kanalı sistemlerinin test prosedürü ve metotları.

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NOMENCLATURE

A	Area, m^2
c	Proportionality constant
C	Leakage rate coefficient, L/s
C^*	Specific Leakage rate coefficient, L/s/m
e_l	Loss coefficient for laminar flow
e_t	Loss coefficient for turbulent flow
f_{ref}	Leakage factor at a reference pressure, $m^3/s/m^2$
L	Length of duct section, m
n	Exponent from the power law leakage
p	Static pressure, Pa
Δp^*	Normalized pressure difference, $=\Delta p / \Delta p_{ref}$
Δp_{ref}	Reference pressure difference, 250Pa
q_{vl}	Leakage volume flow rate, m^3 /s
Q	Volume flow rate, m^3/h
V	Velocity, m/s
α	Angle, °
m_d	Mass of duct, kg
m_{test}	Mass of test load, kg

Greek Letters

ρ	density, kg/m^3

Subscripts

1	Inlet
2	Outlet
ave	Average value
i	Site quantity
max	Maximum value
min	Minimum value

Chapter 1

INTRODUCTION

The primary function of a building is to provide occupants with an environment that is suitable for their activities and well being. In fulfilling this role, outdoor perturbations and internal loads must be processed to achieve a good indoor climate. However, because there are a number of underlying issues, space conditioning in buildings has been given increased attention over the past few years in Europe. In addition, climate control is strongly related to public health and productivity concerns and recent studies, in Europe, suggest that it has an effect on measures of productivity such as absence from work or health costs. These usually lie between 5% and 15% respectively [1]. These ranges may be more in Turkey, due to traditions in the design and installation of climate control systems in Turkey.

Therefore, the efficiency of air distribution systems is a very active field of investigation. These systems are often used in buildings as a strategy to control thermal conditions and indoor air quality. Many problems have been reported in relation to energy use and peak power demand, clean air supply, flow balancing and airtightness etc. Duct leakage in air distribution systems can cause indoor air quality problems. Even small leaks in ductwork can waste a lot of energy, too. Leaking ductwork can reduce overall efficiency of heating and cooling systems by 20% to 40% in buildings [2].

1.1. Airtightness of Air Distribution System

Air distribution system represents a key parameter for achieving a good indoor climate; increased attention has been given their performance during the past few years. Several studies have shown that duct leaks can significantly affect the ventilation rates in a building, which in turn modifies the amount of energy used for heating or cooling [3]. Furthermore, as the fan power demand is a function of the airflow rate passing through it, additional energy losses may occur due to inadequate sizing and leakage airflow compensation. Poor airtightness can also contribute to the entry of pollutants and insufficient ‘effective’ ventilation rates. Leaks from air distribution systems are caused poor indoor air quality, and additional energy losses. As a result of this situation, operational costs are increased. In summary, duct leakage is detrimental to energy efficiency, comfort effectiveness and indoor air quality. This relation is shown as below:

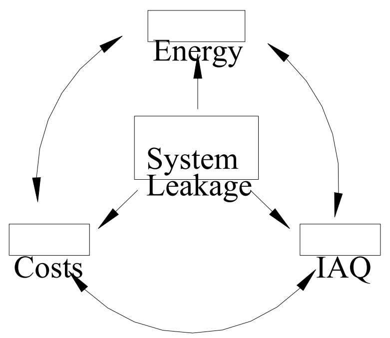


Figure 1.1 System Leakage Effects [3]

The achievement of an acceptable indoor air quality is the first priority, ventilation being essential in most circumstances. A limited energy use is an important boundary condition. Poor ductwork performances will have a negative influence on both the indoor air quality and the energy use of building.

Indoor air quality is important because the health and the comfort of people working indoors are important, as well, some building owners interested in indoor air quality make this a top priority today, because a work environment that causes discomfort or health problems (often leading to absenteeism) results in a loss of productivity.

1.1.1. Integrating the Ductwork Airtightness in the System Performance

Although some adjustment are needed, currently used leakage tests that express requirements in terms of the leakage factor appear satisfactory for industry standards for sheet metal ducts as they are compatible with product certification constraints and may be checked on site.

However, integrated ductwork leakage in the system performance goes beyond performing “classical” leakage tests as the way the whole system operates should be taken into account. In principle, performance test should apply to all types of systems (sheet-metal, fibre- glass board, etc.). It appears natural to express leakage flows as a percentage of the delivered airflow. This system performance approach appears as a very attractive measure towards energy efficiency. Duct leakage requirements could be as follows;

Table 1.1 System Classes and Corresponding Leakage Values [4].

System Class	Maximum value of leakage flow divided by delivered airflow (%)	Increase of fan power demand (%) (Assuming cube law)
I	6 %	20 %
II	2 %	6 %
III	2/3 %	2 %
IV	2/9 %	0.7 %

It should be note that as there is no direct relationship between the delivered airflow rate and the system's surface area, the leakage factor concept (on which are based on Eurovent tightness classes) cannot be directly utilized. At the design stage however, a leakage factor class requirement can easily be derived from the desired system class. Thus, there should not be any difficulties to go back and forth between leakage factor and system classes. Duct leakage requirements are also proposed as depend on pressure classes:

Table 1.2 Pressure Classes and Corresponding Leakage Values [5].

Duct Pressure Class	Maximum value of leakage flow divided by total airflow (%)
Low Pressure	6 %
Medium Pressure	3 %
High Pressure	2% - 0.5%

Thus, designer can decide pressure and leakage class by knowing maximum value of leakage flow.

The management of air distribution system is a serious task that involves some knowledge on health, and technical background on the operation and maintenance of such systems. Therefore, it certainly deserves a higher status than at present. Also, the technicians whose task is to ensure the proper functioning of these systems should be trained adequately.

1.2. Tradition in the Design

Duct system designs can very considerable depend on the building type (single-family houses, multi-family buildings, or commercial buildings) and local customs. This may have a negative impact on the system's operation and maintenance because of the wide price and performance range of the many commercially available products. Traditions in the installation (that differ considerably between countries) can also contribute to poor performance.

Inadequate product selection and poor installation can severely affect the airtightness of an HVAC system. Special attention should be paid to the connection parts and the connection themselves since these are the weakest points. Also, some (complex) components (e.g. air handling unit) are very difficult to get airtight. Conversely, it is fairly easy to have airtight straight ducts (either rectangular or circular) provided that the accessibility and the durability of the sealing media be taken into account. Professionals generally agree with this, although they do not seem to be quite aware of how leaky components can be.

Insufficient care when maintaining and/or inspecting an installation can also lead to poor airtightness. Although professionals consider that inspection hatches do not include significant leakage, they are sometimes found improperly sealed after a cleaning procedure.

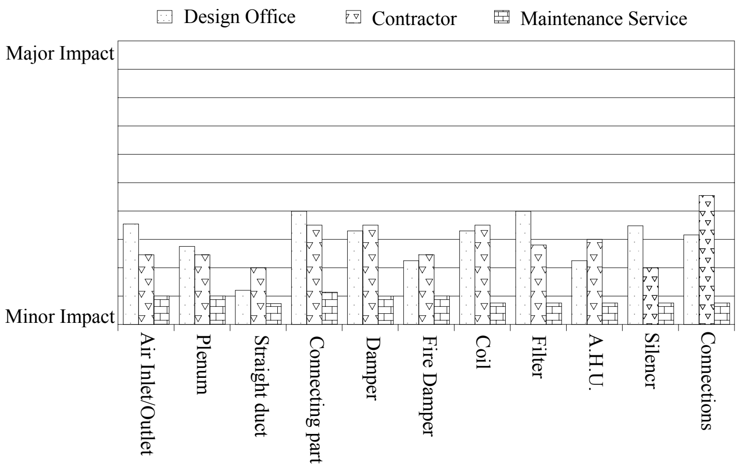


Figure 1.2 Perceived impact of several components on duct leakage [4]

1.3. Overview of Duct Leakage Status in Europe and Turkey

In Europe, it is found that the ratio between the average leakage airflow rate and the nominal airflow rate measured in commercial and institutional buildings was an average of %13 at the pressure of 50 Pa and an average of %21 at the pressure of 100 Pa [4]. According to the study, there are 50 million office workers and 150 million dwellings in Europe and heating energy consumption due to leaks are 3 TWh/year and 150 TWh/year in offices and dwellings respectively.

In Turkey, certain leakage limits for ducts and procedures for testing ducts are identified by Institute of Turkish Standards (TSE). But, many manufacturers do not apply TSE specifications to perform their products. Furthermore, there is not enough research on the energy losses of ducts in Turkey. If results for Europe are considered, it will be guessed that heating energy consumption due to leaks in Turkey is higher than Europe.

Air leakage in sheet metal ducts depends on the specific geometry of the joint and seams, the sealing used, and the pressure difference from the inside to the outside of the duct. Predicting leakage has been difficult due to the lack of consistent data for contemporary duct systems and components. Recognizing this difficulty, Ashare's Technical Committee 5.2 (Duct Design) sponsored several studies aimed at providing improved duct leakage data. The study reported herein was adapted from that effort. Working under the technical oversight of standards, a laboratory duct leakage measurement system was developed and applied to measure the total leakage rates and the leakage of the joints and seams [6,7].

1.4. Aim and Method of the Study

The main purpose of this study is to give an overview of air distribution system with a special focus on air leakage and to research manufacturing methods for airtightness with various cross-sectioned air ducts. This study provides three primary objectives; (1) Searching for air leakage from duct system components and quality requirements based on airtightness; (2) Air leakage detection for various cross sectioned air ducts; (3) Research on manufacturing methods for airtightness.

Chapter 2 consists of four parts; components of duct system, energy losses in duct system, ductwork classification and quality requirements for airtightness ductwork systems. This chapter starts with the importance of ductwork system for indoor air quality and continuous with the effects of its components on air leakage.

The purpose of Chapter 3 is to give an overview of standards in the different countries related to the airtightness. Therefore, Eurovent, Smacna, DW144, Ashrae, DIN, EN and TSE standards are described.

Chapter 4 constitutes the study with the title of “duct leakage model”. It is divided into two parts; the first part explains the leakage model for a single duct while the second part explains for a branched duct system.

Chapter 5, focusing on test system and procedure, has an aim of understanding the how all ducts are tested. Two approaches are chosen for leakage through duct system measurements. First approach is based on Eurovent Standard. For the second approach, the duct system is divided into single sections between fittings and the leakage rate for each section is calculated by the Power Law Model. In this study, leakage measurements were made on different types of duct and duct system by using a test apparatus based on TSE and Europe Standards.

Chapter 6 gives test results with graphics and tables and suggestions for manufacturing methods. In Chapter 7, all test results are discussed.

Chapter 2

DUCT SYSTEMS

The purpose of heating, ventilating and air conditioning (HVAC) duct system is to provide building occupants with thermal comfort However a poorly designed or constructed HVAC duct system may result discomfort, that are noisy and that permit contamination to occur to the conditioned spaces. Figure 1 shows a common duct system.

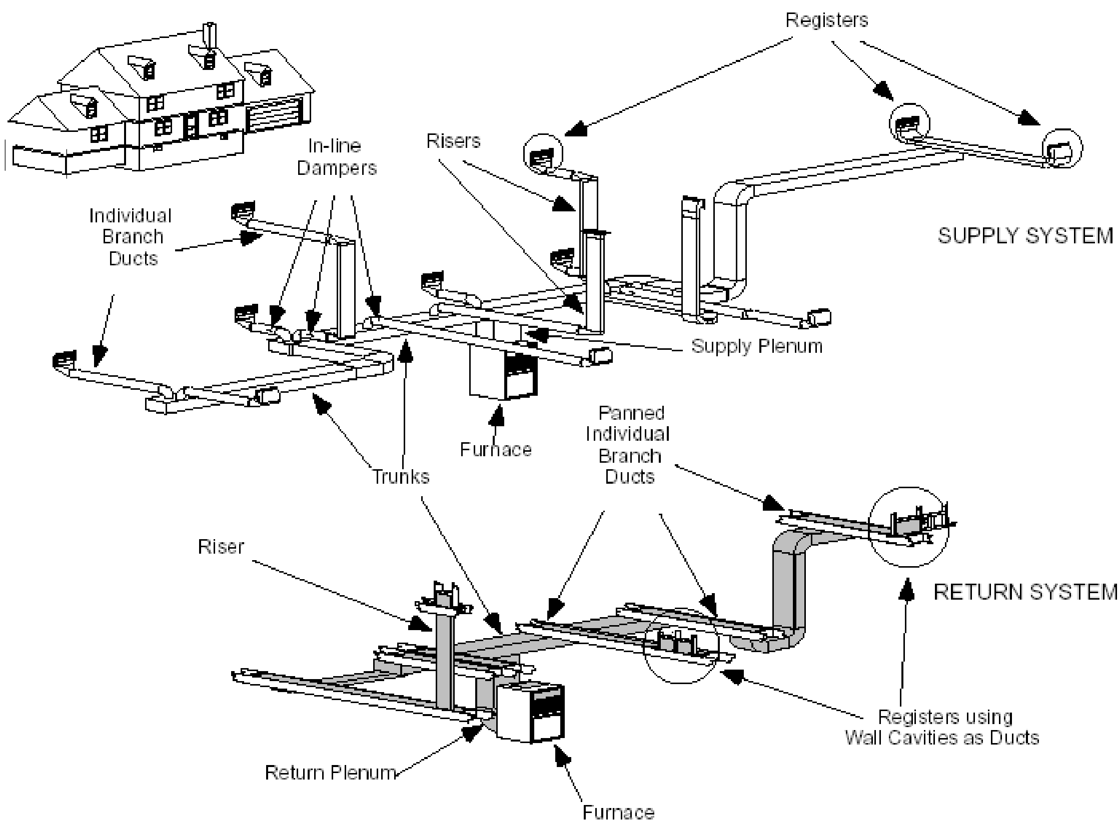


Figure 2.1 Common Duct Systems [8]

Duct systems are used in buildings to transport conditioned air between heating and cooling equipment and the occupied space. Ducts also distribute outdoor air to the occupied space and exhaust indoor air to outdoors. The duct system has an important effect on health of the occupants through the distribution of indoor air pollution.

2.1. Components of Duct System

In large commercial buildings, with spaces larger than approximately 1000 m^2 served by air-handling systems. The larger ducts with cross-section dimensions up to several meters, are usually constructed from sheet metal or from a rigid fiberglass material, sometimes called fiberglass duct board. Smaller ducts, often with a diameter of 15-to 30 cm connected to air-supply registers may be flexible ducts, containing a helically wound wire structural rigidity, a layer of coated nonrigid fiberglass and an exterior plastic sheet [9]. Duct systems in large commercial buildings may include a large variety of components such as dampers, turning vanes, variable-air-volume-control units, cooling or heating coils, supply and return registers, and sensors for temperature, humidity, smoke, carbon dioxide concentration, pressure, and flow rate.

A duct system is a branching networks of round or rectangular tubes-generally constructed of sheet metal, fiberglass board, or a flexible plastic and wire composite-located within the walls, floors, and ceilings. Usually it is seen only the outlet, which is a register covered with grillwork. This system consists of supply and return ducts. Central heating or cooling equipment (furnace, air conditioner or heat pump) contains a fan that forces heated or cooled air into supply ducts leading to the rooms. The fan gets its air supply through return ducts, which in the best system are installed every room of the house. Duct systems are usually constructed of many interconnected duct sections, and the junctions between sections are often locations of air leakage [10].

2.2. Energy Losses in Duct System

Typical duct systems lose %2 to %40 of the heating or cooling energy put out by the central furnace, heat pump, or air conditioner [8]. Homes with ducts in a protected area such as a basement may lose somewhat less than this, while some other types of systems (such as attic ducts in hot, humid climates) often lose more.Duct systems lose energy in two ways; by conduction of heat from the warm surface, and air leakage through small cracks and seams.

2.2.1. Conduction and Convection Losses

One source of energy losses in duct systems is the conductive and connective heat transfer between the air inside ducts and the surrounding air. To reduce the rate of conductive losses in sheet metal ducts, and for acoustic control, these ducts may have a layer of external or internal insulation. Commonly, only a portion of the ductwork is insulated.

In homes, if the ducts are in an attic or vented crawl space that is nearly as cold as the outdoors, this heat is completely lost. If the ducts are in a basement, some of the heat lost from the ducts may be recaptured by warming the basement ceiling enough to reduce the heat lost from the house.

2.2.2. Air Leakage

Another way that duct lose energy is through air leakage. Sometimes this leakage is from accidental holes in the ducts or poorly connected duct sections; but even if the ducts are sealed, their operation can cause the house itself to leak more air than would otherwise be the case.

An understanding of pressure differences in the duct system helps to better understand air leakage in the buildings. Air moves from high pressure to low pressure. To get air move from the supply duct into the room it serves, the air in the duct has to be at a higher pressure than the air in the room. Similarly, to move air from the room into the return duct, the air in that duct has to be at a lower pressure than the air in the room [11].

Air leakage into or out of ducts is important source of energy losses. Air leakage rates in commercial buildings duct systems are very difficult to measure accurately; however, a synthesis of measurements from a set of light commercial buildings in California suggest an average leakage rate in supply ducts of approximately 25% of the flow through the supply fan [8]. For example, in field studies of light commercial buildings determined that the cooling capacity of air delivered through supply registers decreased by 10% to 40% due to conduction losses [8]. The associated temperature increases in the supply air streams, between the supply plenums and the supply registers, ranged from 0.5 to 6 ºC.

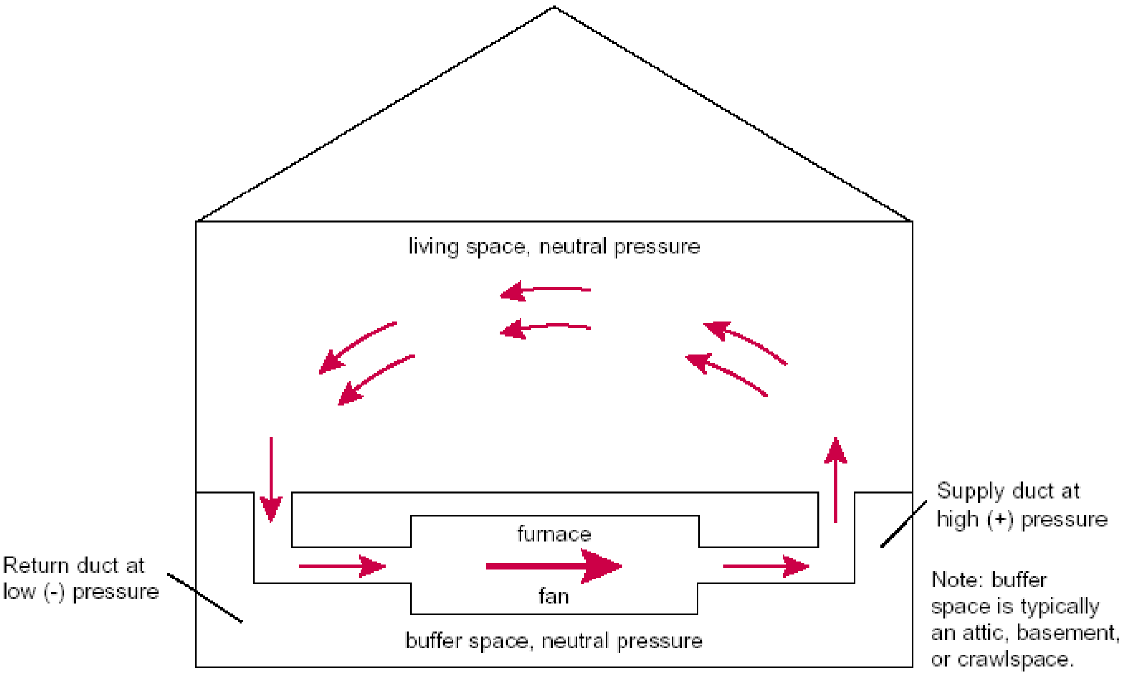


Figure 2.2 Ideal Duct Schematic with no leakage [8]

Figure 2.2 shows a duct system that does not leak. The furnace fan produces a high pressure in the supply ducts and a low pressure in the return ducts. The high-pressure forces warm air from the supply ducts to flow into the rooms, and low pressure draws room air back into the return ducts.

Designer and fabricators of heating, ventilation, air conditioning systems in large commercial buildings have often been unconcerned about energy losses caused by air leakage or heat conduction, because these ducts are typically located inside the conditioned interior of the building. However, conduction losses and leakage will increase HVAC energy use even when ducts are located in the conditioned space. For example, to overcome the leakage and conduction losses and maintain indoor thermal conditions at set points, the rates of airflow through fans must often be increased, leading to an increase in fan energy. As fan energy use increases, the amount of fan heat that must be removed by the cooling system also increases. The influence of air leakage and conduction losses on HVAC energy use will depend on many factors, including the method of air flow control in the HVAC system, the locations of air leaks, and the locations of ducts. As an example of energy impacts is a 65% increase in fan energy and a 10% increase in cooling coil loads when 20% of the supply air leaks from the supply ducts of a variable air volume (VAV) system with the fan speed controlled by a variable speed drive [3].

2.3. Ductwork Classification

Air ducts are classified as their shapes and as their construction of materials into two groups.

2.3.1. Construction of Materials

Metal is the most frequently used material either for rectangular or round ducts. Plastic is another material that is often used in single-family houses, as it is cheap and compatible with the fire regulations for air ducts. On the other hand, fiberglass boards and brick are not used very much. The reason certainly lies in health and safety issues. Note that in several European countries blowing air through fiberglass ductwork is forbidden.

Air ducts are made from different materials depend on field application and cost. These are; galvanized steel sheet, carbon steel sheet, aluminum sheet, stainless steel, and copper sheet.

a. Galvanized sheet ductwork generally finds applications in comfort climate and ventilation installations and rarely in industrial applications. Galvanized sheet metal ductwork can be used in systems which to cause corrosion and hazardous materials are not contained in moved air. The temperature of the moved air should be under 200 °C. When the air temperature is approximately 200°C, the risk of corrosion will be increase.

b. Carbon steel sheet ductwork is used in systems which high temperature resistance and painted or coated ducts are demanded such as kitchen exhaust systems, smoke transportation, chimney.

c. Aluminum sheet ductwork is used in systems which high atmospheric corrosion resistance is demanded. In choosing high-pressure systems, it is necessary to consider thickness and resistance of aluminum.

d. Stainless steel ductwork is particularly suited include those where a high integrity inert material is essential; where a high degree of hygiene is required; in the chemical industries where toxic or hazardous materials may be contained; in nuclear and marine applications (e.g., on offshore platforms). Stainless steels also find application in exposed ductwork where their finish can be used to aesthetic advantage.

e. Copper sheet ductwork is useful for systems including chemicals to which cupper is resistant. In the system, it is necessary to consider pressure range.

2.3.2. Shape of Air Ducts

Both designers and contractors would rather use round ducts as they are manufactured with standard sizes. However, the market penetration of rectangular ducts is significant in our country.

a. Circular ducts have the most suitable air flow profile in the ducts. That's why, it is possible to reach higher air velocity at mean pressure values in circular ducts and also noise level is lower opposite to rectangular ducts. Generally, circular ducts are manufactured in a factory. Circular fittings are used for duct-to-duct connections in system installations. Spirally wound ducts as a construction of circular ducts are rather used in our country.

b. Flat oval ducts with opposed sides and semi-circular ends causes a good airflow in ducts. That's why, pressure losses in the duct system can be reduced. Flat oval ducts are suited where the height of ceiling is limited.

c. Rectangular ducts are manufactured with different cross-joints. Those are drive slip cross-joints, stiffener cross-joints, and side-on flanged cross-joints. Flanged joints and self-flanged joints are mostly used for rectangular duct connections.

2.4. Quality Requirements for Ductwork Systems

The key role of air distribution system is to provide clean air to conditions spaces. It is important to have a properly designed ductwork:

- It shall be tight and secure the air transport through the system;
- It shall have such a heat resistance that energy losses are restricted;
- The system shall have a low resistance to the flow to minimize the fan power demand and energy use;

- Components shall be laid so that they are accessible for cleaning and shall, if necessary, be supplied with cleaning facilities;
- They have to be able to withstand normal handling and installation stresses as well as the positive or negative operating pressure of the system in which they will be integrated;
- Noise should be prevented from getting through to the occupied spaces;
- Duct system shall not contribute to the spread of fire, smoke or gases;
- The materials should be chosen according to the aggressiveness of the environment to limit corrosion damages;
- The ductwork shall be safe and easy to install;
- It should preferably use standard sizes, facilitating prefabrication of ducts and components, thus allowing for shorter delivery times and possibly lower costs.

In most of the member states, it is commonly accepted that the ductwork airtightness is not a key issue to efficiently distribute the air within the building and thus leakage tests are viewed as an unnecessary expense. However, as stated in Eurovent Guidelines 2/2, a ductwork airtightness limit may be required to minimize the cost and the energy penalty due to an over-sized or inefficient plant, and/or to ease the flow balancing process, and/or to have control over the leakage noise. Other impacts such as the entry or release of pollutants through leaks or the in/ex filtration to unconditioned spaces can be foreseen, with potentially large effect on energy use, power demand, indoor air quality, and comfort-effectiveness [4,12].

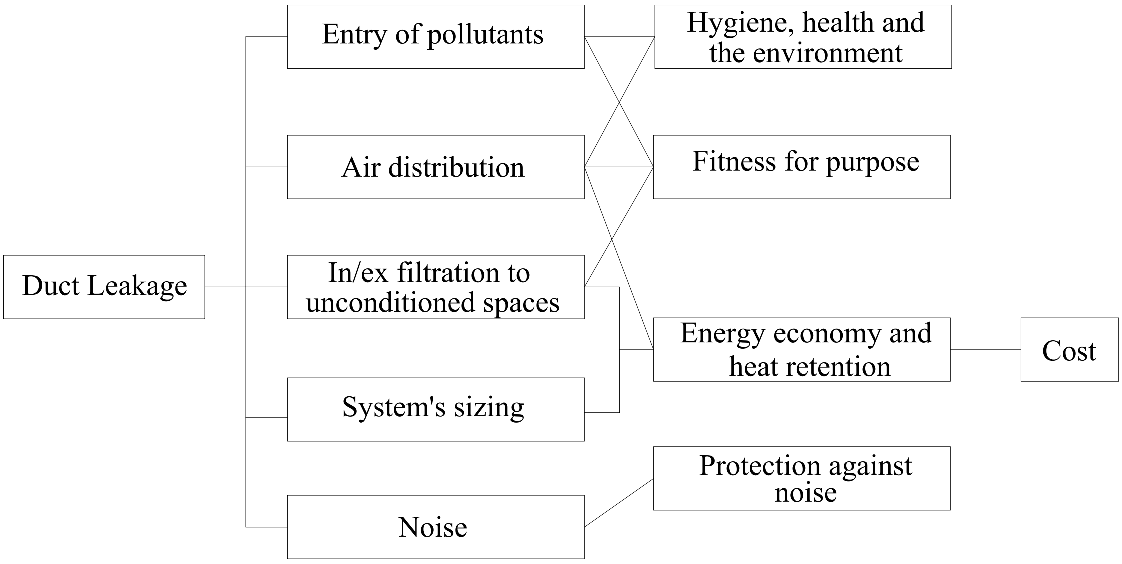


Figure 2.3 Flow chart of duct leakage implications [6]

To provide a general picture, duct leakage implications are represented schematically in Figure 2.3. To avoid these problems, the use of quality commercially available products should be considered and particular attention should be paid to the installation process.

2.4.1. Design

Early in the design phase, it is often possible to choose between different design alternatives. For ventilation design, one early decision is whether to use round or rectangular ductwork or more often to use a suitable combination between the two. The advantages with the round system include:

- Connecting two circular spiral wound ducts only requires one fitting, whereas rectangular ducts are connected by use of a completely separate flanging system. The round ducts can have any length between the connections, a duct length of 3 m is standard but 6 m is also frequently used. On the other hand, the length of a rectangular duct is limited by the size of the steel sheet usually to less than 2 m and therefore requires many more connections [4];

- Round ducts are tighter. Larger duct systems (≥50m² duct surface area) are, according to VVS AMA 83(1984), required to be three times tighter than a rectangular duct system [4];

- The installation cost is normally lower, at least in countries where round ducts have been in use for a longer period of time. The overall cost of a duct system built with circular ducts is distinctly lower than one with rectangular ducts;
- The installation is simpler to carry out and the installation time for a circular duct system is normally shorter, sometimes only a third of that for a similar rectangular system;
- The pressure drop in circular duct system is often lower than in a rectangular duct at the same air velocity due to industrially manufactured and more aerodynamically designed duct components such as elbows and branches;
- The noise generated in straight ducts is normally of no significance while the noise generated in elbows might cause problems at higher air velocities. Circular duct components have normally known properties while "tailor-made" parts in rectangular ducts are less well known;
- The circular duct wall is stiffer than the rectangular one and thus will allow less sound transmission through the duct wall. Whether this is an advantage or not must be considered case by case;
- The weight of the round system is lower. Thus, the amount of steel needed is smaller, which, on a larger scale, has environmental benefits;
- Ductwork is measured and tailor-made for each installation. Using round ductwork with standard sizes (the diameters of the ducts increase by 25% upwards: 80, 100, 125, 250, mm etc.) normally decreases the waste when the ducts do not fit. The round duct or component does not have to be scrapped, it can be used somewhere else in the building there are probably plenty of ducts of the same diameter.

The main advantage with a rectangular duct is that, for the same free cross-area, it can be flattened. In buildings with restricted room heights it could thus be easer to cross underneath beams and other space restrictions. On the other hand, if considered early in the design phase, it might be possible to use parallel round ducts instead of a flat rectangular one. Normally the best solution is a compromise between round and rectangular. For example, rectangular ducts might be used at the start of the system (near the fan), where the airflow ducts are large. Further on, with the airflow being distributed to smaller ducts, the ducts should be round.

Chapter 3

REVIEW OF THE STANDARDS

This chapter gives an overview of standards and building regulations related to the airtightness of air distribution system in Europe. It looks at existing standards as well as those currently under preparation at the European level.

3.1. Eurovent Guidelines 2/2

Eurovent is the European Committee of Air Handling and Air Conditioning Equipment Manufacturers [12]. It was created in 1959 and the following countries are members of this committee: Belgium, Finland, France, Germany, Great Britain, Italy, Netherlands, Norway, Sweden and Turkey.

3.1.1. Leakage Factor

The leakage factor is the leakage flow rate at a known static pressure per m² of duct surface area:

$$f_{ref} = \frac{q_{vl}}{A} \qquad (3.1)$$

where:

f_{ref} is the leakage factor at a reference pressure Δp_{ref} ($m^3\ s^{-1}\ m^{-2}$);

q_{vl} is the leakage volume flow rate ($m^3\ s^{-1}$);

A is the duct surface area (m^2).

The leakage factor depends on the pressure Δp_{ref} at which the leakage airflow rate is measured. According to this document, it shall be set to the arithmetical mean value of maximum and minimum values of static pressure difference in Pa across the ductwork.

3.1.2. Leakage Classes

This document defines three classes of airtightness (A, B, and C) for normal ventilating and air-conditioning installations. The classification is based on quantity:

$$K = \frac{f_{ref}}{\Delta p_{ref}^{\ 0,65}} \tag{3.2}$$

where:

K is the leakage coefficient per m^2 of duct surface area ($m^3\ s^{-1}\ m^{-2}\ Pa^{-0,65}$).

0.65 is an arbitrary flow exponent which according to DW /143 is justified by Swedish test performed on a variety of constructions.

This quantity gives a measure of the ductwork leakage, which should be independent of the static test pressure in the ductwork. The next table gives the upper limits of this quantity for the three different classes.

Table 3.1 Airtightness classes defined within the Eurovent Guidelines 2/2 [12]

Class A	$K_A =$	$0.027 \cdot 10^{-3}$ $m^3\ s^{-1}\ m^{-2}\ Pa^{-0,65}$
Class B	$K_B =$	$0.009 \cdot 10^{-3}$ $m^3\ s^{-1}\ m^{-2}\ Pa^{-0,65}$
Class C	$K_C =$	$0.003 \cdot 10^{-3}$ $m^3\ s^{-1}\ m^{-2}\ Pa^{-0,65}$

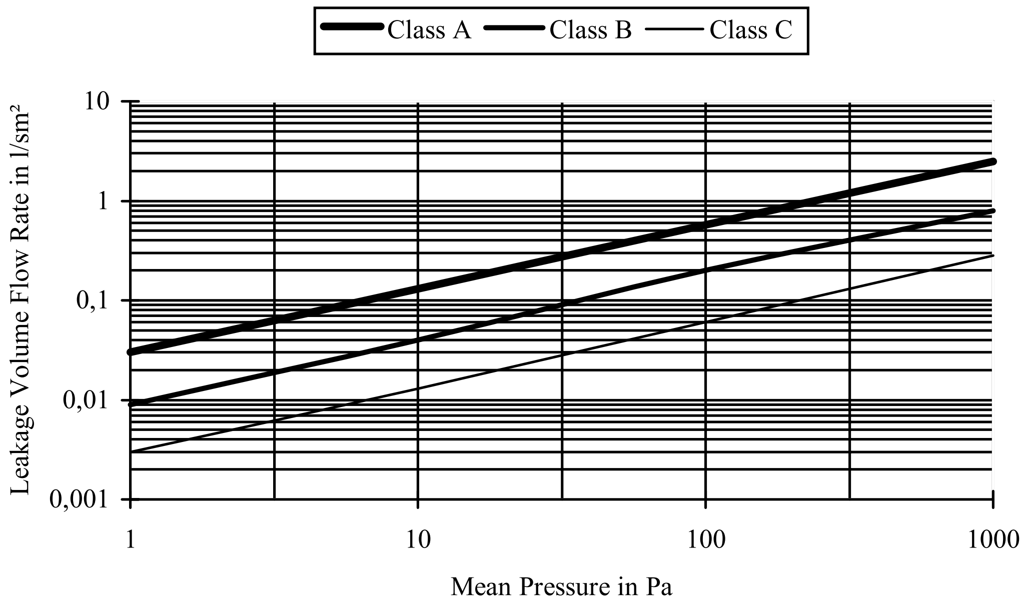


Figure 3.1 Leakage flow per m² duct area as a function of the mean static pressure [12]

Also, a graph included in this document enables the test operator to calculate:

- The leakage airflow as a function of the mean pressure and the duct leakage;
- The leakage airflow as a percentage of system airflow rates.

3.1.3. Testing

Fan pressurization method is chosen in this standard. The ends of the test section are sealed. Then, the leakage factor is determined by artificially creating a pressure differential in the test section and by measuring the leakage flow rate.

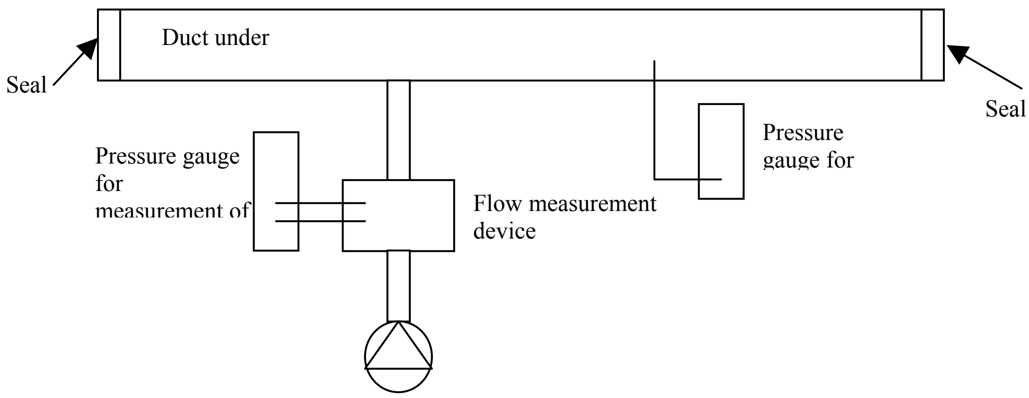


Figure 3.2 Ductwork leakage testing with fan pressurization technique [12]

Test pressure for Class A and B ductwork should not exceed 1000 Pa or the maximum design static gauge duct pressure, whichever the smaller. For Class C ductwork, the pressure can be increased to 2000 Pa. The test pressure shall not be less than the design operating pressure. The next table gives the upper limits of the leakage volume flow rate for the 3 classes at typical test pressures.

Table 3.2 Maximum leakage for the three classes and for typical test pressures [12]

Class	Maximum leakage factor ($m^3s^{-1}m^{-2}$)	Test static pressure difference (Pa)			
		2000 Pa	1000 Pa	400 Pa	200 Pa
A	f_A	-	2.4 x 10-3	1.32 x 10-3	0.84 x 10-3
B	f_B	-	0.8 x 10-3	0.44 x 10-3	0.28 x 10-3
C	f_C	0.42 x 10-3	0.28 x 10-3	0.15 x 10-3	-

Test procedure for circular ducts at least 10 % of the total surface shall be tested, and for rectangular ducts at least 20 % shall be tested. In either case the area to be tested shall normally be at least 10 m^2. It is noteworthy that there is no specific information on the duct surface area measurement. If the air leakage rate does not comply with the Class requirement, the test shall be extended to include an additional equal percentage of the total surface area. If the system is still too leaky, the total area shall be tested.

3.2. Smacna Guidelines

Smacna is the Sheet Metal and Air Conditioning Contractors National Association [13]. It was created in 1985 and European countries introduced an evaluation approach using the surface area of the duct and the pressure in the duct as the basic parameters. The foreword of the Smacna guidelines mentions: leakage should be considered a transmission loss in duct systems [13,14]. Key variables that affect the amount of leakage are; static pressure, the amount of duct, the openings in the duct surface, workmanship

3.2.1. Leakage Factor

Within acceptable tolerances, A duct surface leakage factor can be identified by the following relationship:

$$F = C_L * P^N \tag{3.3}$$

where:

F is a leak rate per unit of duct surface area ;

C_L is a constant;

P is static pressure;

N is an exponent;

This relationship in Metric System is occurred as below:

$$F = C_L * P^{0,65} * 0.0223 \tag{3.4}$$

where:

F is a leak rate per unit of duct surface area (m^3/hm^2);

C_L is a constant;

P is static pressure (mmSS).

3.2.2. Leakage Classes

This document defines three classes of airtightness (A, B and C). They are associated with duct type, seal classes and construction pressure classes in the following table:

Table 3.3 Leakage Classes Defined within Smacna [14]

Duct class	50 mmSS	75 mmSS	100 mmSS
Seal Class	C	B	A
Sealing Applicable	Transverse Joints only	Transverse Joints and Seams	Joints, Seams, and All Wall Penetrations
Leakage Class			
Rectangular Metal (C_L)	24	12	6
Round Metal (C_L)	12	6	3

3.2.3. Testing

The designer specifies the fan velocity (m^3/h), the test pressure and the leakage class. The allowable leakage factor is calculated from Equation 4 by multiplying the surface area.

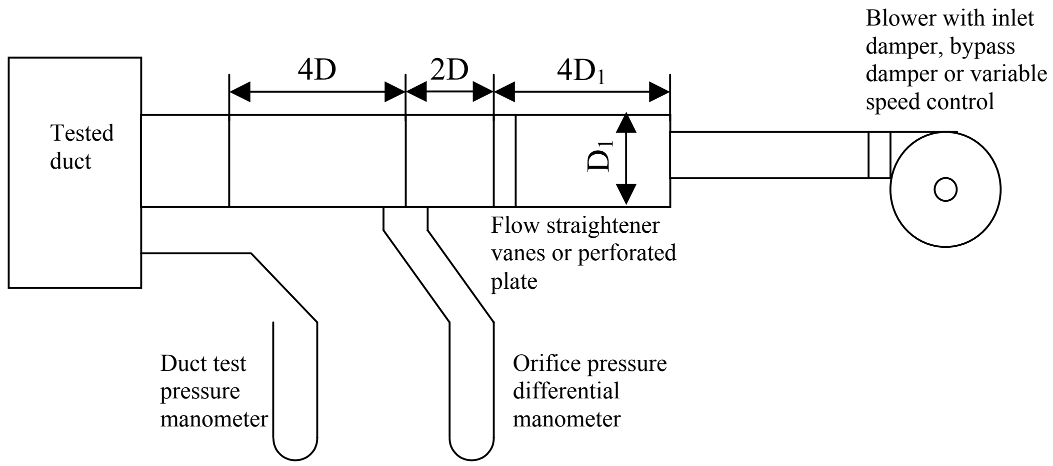


Figure 3.3 Ductwork leakage testing within Smacna [13]

The allowable leakage factor is compared with calculated leakage factor from test results. If the sum of the velocity is measured less than or equal sum of the allowable leakage, the test is passed.

3.3. DW 144

DW/142 was the reference document until 1998, has been reissued as DW/144 [15]. DW/144 gives a classification of ductwork airtightness according to the CEN documents and is a standard in United Kingdom. DW/144 describes also in detail requirements for seams, cross-joints, fastenings, and different types of ductwork.

3.3.1. The Leakage Factor and Leakage Classes

The requirements for the airtightness of the ductwork mentioned in DW/144 depend on the operating pressure:

Table 3.4 Leakage Limits for Different Pressure Classes within DW 144 [15]

Duct Pressure Class	Static Pressure Difference Limit		Maximum Air Velocity (m/s)	Air Leakage Limit (l / s per m^2)
	Positive (Pa)	Negative (Pa)		
Class A–Low Pressure	500	500	10	$0.027*\Delta P^{0,65}$
Class B–Medium Pressure	1000	750	20	$0.009*\Delta P^{0,65}$
Class C–High Pressure	2000	750	40	$0.003*\Delta P^{0,65}$

3.3.2. Testing

The testing should be performed according to DW/143 named ‘A practical guide to ductwork leakage testing’. The following duct areas to be tested during an air leakage measurement are recommended:

- High pressure ducts: whole area tested;
- Medium pressure ducts: 10 % of the ductwork randomly selected and tested;

- Low pressure ducts: untested.

According to DW/143, air leakage as a percentage of total airflow is mentioned within 6% for the low-pressure class and 3% for the medium-pressure class. For the high-pressure class, air loss is likely to be between 2% and 0.5%, according to which leakage limit is applied.

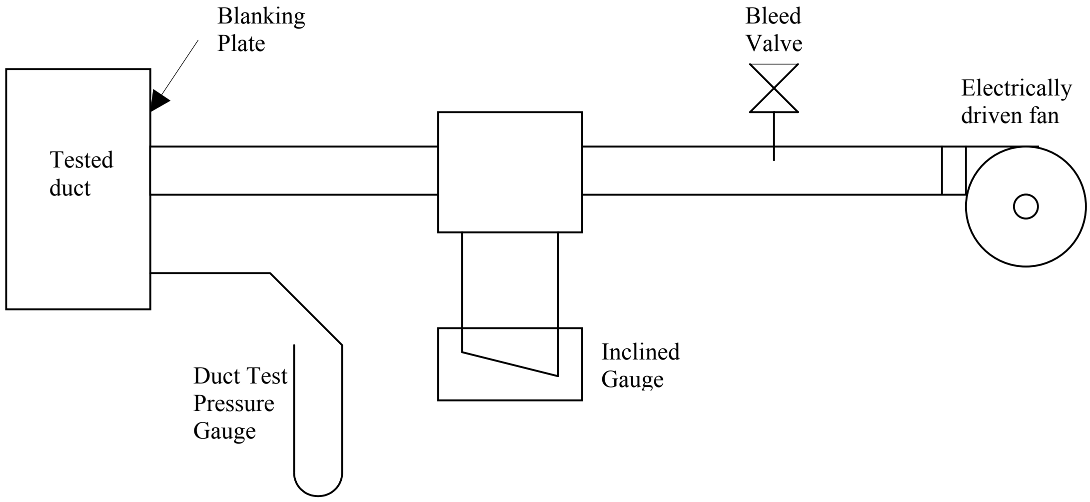


Figure 3.4 Typical Apparatus for Air Leakage Test within DW 143 [15]

3.4. ASHRAE Standard 152P

ASHRAE Standard 152P describes in a detailed way the test method for determining the design and seasonal efficiencies of residential thermal distribution systems [16]. The standard describes a method to determine the leakage airflow rate of the duct system to outside. Briefly, the method consist of the following steps:

- Measurements of the leakage airflow rate of exhaust and supply ductwork to outside, for a pressure of 25 Pa (positive and negative). Therefore the building is first pressurized with a blower door and then the pressure between the building and the ductwork is brought the zero by regulating the speed of the fan for the duct pressurization. The measured flow through the fan connected to the duct is the duct leakage to outside [16];

- Determination of the operating pressure as the average of the pressure at the different registers,

- Conversion of the measured duct leakage airflow to the leakage airflow at operating pressure.

3.5. DIN V 24194 Guidelines

In Smacna and DW /142 is determined the air leakage limits according to Seal Classes of ducts. However there is no information about which criteria is accepted for which application. The study on this problem is just present in DIN norms [5].

Table 3.5 Duct Leakage Classes for Different Test Pressure within DIN V 24194 [5]

Seal Class	Applications	Test Pressure 200 Pa	Test Pressure 4200 Pa	Test Pressure 1000 Pa
1	Plate-Screws Sheet Ducts, Garage, Atelier, Sport Hall, etc.	---	---	---
2	Plate-Screws Sheet Ducts, Meeting Room, Offices, Rooms in Hospitals	0,84	1,32	2,4
3	Plate-Screws Sheet Ducts or Welds Sheet Ducts, Operating Room	0,28	0,44	0,8
4	Welds Sheet Ducts, Radiation Zones	0,093	0,15	0,27

3.6. European Committee for Standardization (CEN)

CEN is the European organization responsible for the planning, drafting and adoption of standards [4]. The following figure shows the position of the standards related to ductwork airtightness in the field of standards related to mechanical building services within CEN TC 156.

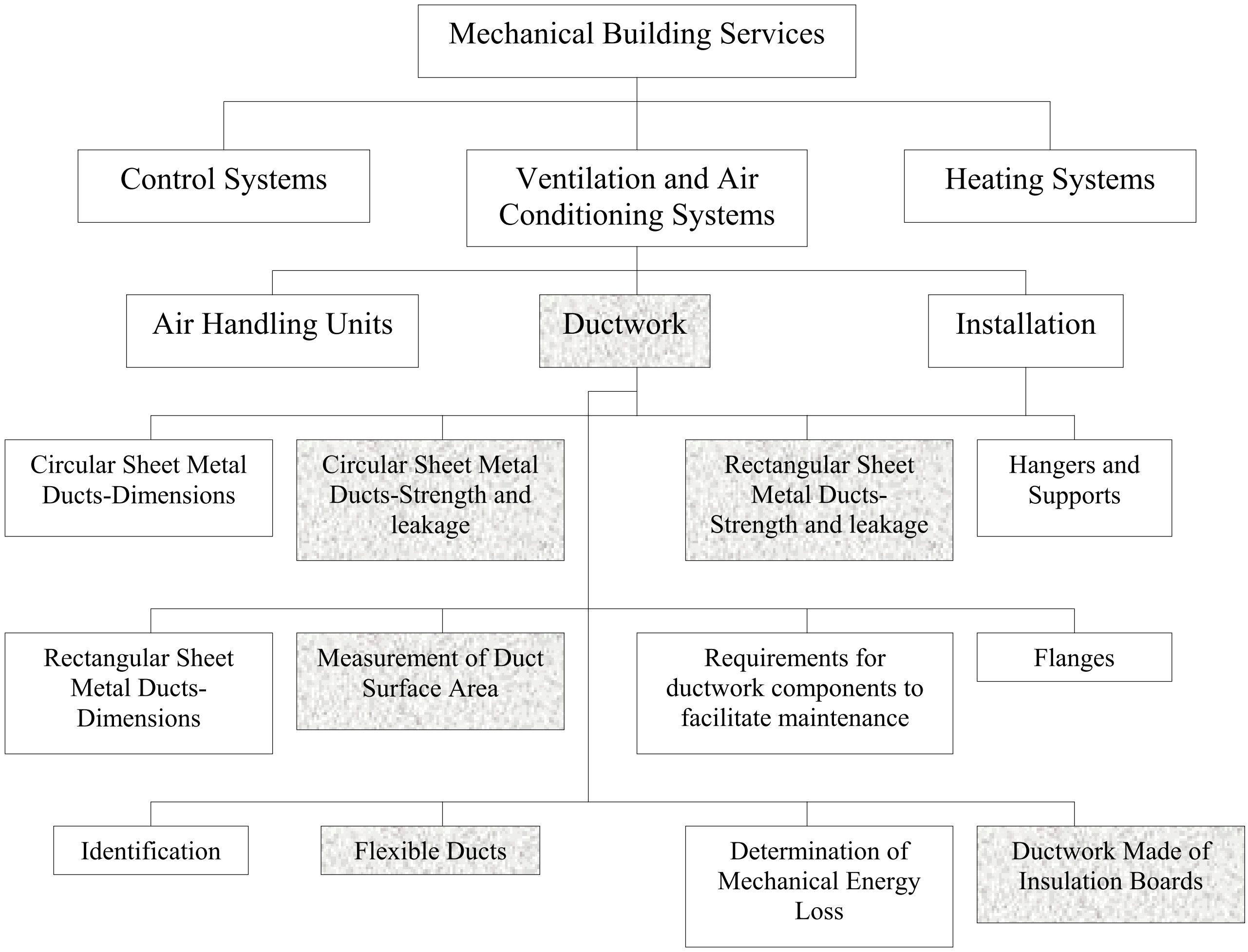


Figure 3.5 Ductwork Airtightness related standards within CEN TC 156 [4]

3.6.1. Circular Sheet Metal Ducts: Strength and leakage – prEN 12237

This standard is specified for the requirements and laboratory test methods for the strength air leakage testing of circular ducts [4]. It is applicable to circular ducts used in the ventilation and air conditioning system in buildings for human occupancy. Primarily, it refers to ducts made from steel, but it is also applicable for other metallic ductwork (e.g. aluminum and copper). The following characteristics are tested or inspected:

- Deflection of the installed duct;
- The air leakage of the duct.

Definition of leakage classes has been adopted from the Eurovent guidelines 2/2 (Table 3.1). The requirement is that the leakage factor shall not exceed 90 % of maximum leakage rate for the applicable tightness class. The standard describes the test equipment:

- Fan with variable airflow rate, with an airflow capacity sufficient to maintain the required pressure level (Table 3.7);
- Airflow meter, with a maximum error of less than 4 % or 0.1 l/s (whichever is the greater value);
- Pressure gauge meter, with an accuracy of 10 Pa or 2 % (whichever is the grater value).

Test procedure to determine the leakage shall be submitted to:

- A certain load, calculated from the mass of the duct (m_d);

  $$m_{test} = m_d + 1.5 \times m_d \tag{3.5}$$

  where $1.5 \times m_d$ is the external loading. This load is foreseen to cover loadings caused by insulation and to give some safety against transport damages.

- A certain pressure, as specified in the following table:

Table 3.6 Test Pressures within CEN TC 156 [4]

Class	Test Static Gauge Pressure			
	1000 Pa		400 Pa	
	+	-	+	-
A			X	X
B	X	X		
C	X	X		

The test pressure has to be maintained until steady state is reached. Then the leakage flow is recorded. The air leakage has to be given as the leakage factor, i.e. the airflow rate divided by the duct surface area. The leakage factor has to be determined with and without load. A test report has to be made, including the following information:

- Manufacturer, number of tested ducts, duct material, design of joints;

- Cross sectional and longitudinal dimensions of the duct and sketch of test arrangement;
- Mass of insulation (if applicable);
- Test load;
- Distance between supports;
- Deflection;
- Ovality;
- Test pressure and leakage factor with and without load;
- Tightness class;
- Time, place and signature.

3.6.2. Rectangular Sheet Metal Ducts: Strength and leakage – prEN 1507

This standard is specified for the requirements and test methods for the strength air leakage testing of rectangular ducts, including joints. As regards duct leakage testing, this standard is very similar to prEN 12237 [4].

3.6.3. Ductwork Made of Insulation Ductboards: prEN 13403

This European Standard contains the basic requirements and characteristics for ductwork made of insulation ductboards, used in ventilation and air conditioning systems of buildings, subject to human occupancy. Ductboard is defined as a rigid board composed of insulation material body with one or both sides faced; ductboards are fabricated into rectangular or multisided duct sections; the outer facing is a duct vapour barrier and is supposed to make the duct airtight. The standard gives requirements regarding maximum air speed, resistance against pressure, airtightness, building and/or caving, supports and hangers, facilities for cleaning and requirements for materials Regarding airtightness, the same requirements apply as in prEN 1507 and prEN 12237 [4].

3.7. Turkish Standards; TS prEN 12237 - TS prEN 1507

This standard specified requirements and test methods for the strength air leakage testing of rectangular and circular ducts, including joints. These standards are adopted from CEN prEN 12237 and CEN prEN 1507.[17].

Chapter 4

DUCT LEAKAGE MODEL

Air leakage in sheet metal ducts depends on the specific geometry of the joint and seams, the sealing used, and the pressure difference from the inside to the outside of the duct. Predicting leakage has been difficult due to the lack of consistent data for contemporary duct systems and components. Leakage from a duct system occurs through the longitudinal seams as well as through the joints connecting the duct sections together. Leakage is driven by the pressure difference across a duct envelope. The pressure forces acting on the fluid at an opening or in a leakage path cause the fluid to flow toward the area of lower pressure. The magnitude of the resulting mean velocity at any point along the path is determined by the difference between the pressure force in the flow direction and the viscous force opposing the motion. The leakage flow rate can be calculated by applying the continuity equation. The product of the local mean velocity in the flow path and the corresponding leakage flow area gives the volume rate of flow. Insight into the leakage process and a useful duct leakage prediction method can be obtained by use of this relationship [18,19].

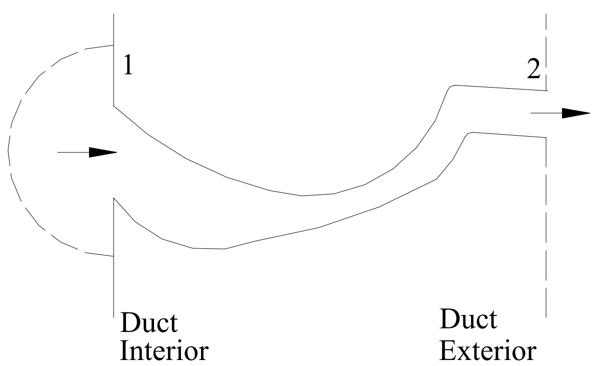


Figure 4.1 Leakage Path [18]

A one-dimensional flow model was applied to an arbitrary leakage path such as that shown in Figure 4.1. The model was developed for steady, incompressible flow from point 1 inside a pressurized duct to point 2 just outside. The energy equation for this leakage flow is simplified to,

$$\frac{p_1}{\rho}+\frac{V_1^2}{2}=\frac{p_2}{\rho}+\frac{V_2^2}{2}+\sum losses \tag{4.1}$$

Rearranging and setting V_1, the leakage velocity inside the duct, to zero and solving for velocity V_2 at the exit plane yields:

$$V_2=\sqrt{2\left[\frac{(p_2-p_1)}{\rho}-\sum losses\right]} \tag{4.2}$$

The (P_1 - P_2) term is the pressure difference from the inside to the outside of the duct and ∑ losses is the sum of the flow losses for a particular leakage path. Application of the continuity equation leads to:

$$Q=\int_A V_{ave}\,dA=\sum_{i=1}^{m} V_i A_i \tag{4.3}$$

where:

Q is air leakage volume flow rate;

A is cross area of the test system;

V_{ave} is average air velocity.

The average velocity can be calculated, in principle:

$$V_{ort}=\frac{\int_A V_{ave}\,dA}{A_{crossarea}}=\frac{\sum_{i=1}^{m} V_i A_i}{A_{crossarea}}=\frac{1}{m}\sum V_i \tag{4.4}$$

4.1. Leakage Model for A Single Duct

According to Eurovent [12], the leakage factor is the leakage flow rate at a known static pressure per m² of duct surface area:

$$f_{ref} = \frac{Q}{A} \tag{4.5}$$

where:

f_{ref} is the leakage factor at a reference pressure Δp_{ref} ($m^3\ s^{-1}\ m^{-2}$);

Q is the leakage volume flow rate ($m^3\ s^{-1}$);

A is the duct surface area (m^2).

The leakage factor depends on the pressure Δp_{ref} at which the leakage airflow rate is measured. According to Eurovent, it shall be set to the arithmetical mean value of maximum and minimum values of static pressure difference across the ductwork (Pa).

Eurovent defines three classes of airtightness (A, B, and C) for normal ventilating and air-conditioning installations. The classification is based on quantity:

$$K = \frac{f_{ref}}{\Delta p_{ref}^{\ 0,65}} \tag{4.6}$$

where:

K is the leakage coefficient per m^2 of duct surface area ($m^3\ s^{-1}\ m^{-2}\ Pa^{-0,65}$).

0,65 is an arbitrary flow exponent which according to DW /143 is justified by Swedish test performed on a variety of constructions.

This quantity gives a measure of the ductwork leakage, which should be independent of the static test pressure in the ductwork. Test results for a single round and rectangular duct were calculated using this model given above. Finally, leakage classes for all ducts were determined by using Eurovent Classes.

4.2. Leakage Model in for Branched Duct System

This model was adapted from Ashrae Research Project-1985 [18]. A difficult problem, however, is the determination of the sum of the flow losses along a specific leakage path.

$$V_2 = \sqrt{2\left[\frac{(p_2 - p_1)}{\rho} - \sum losses\right]} \tag{4.7}$$

The $(P_l - P_2)$ term is the pressure difference from the inside to the outside of the duct and $\sum$ losses is the sum of the flow losses for a particular leakage path. Applying the continuity equation to the exit plane of area A_2, the leakage flow rate, Q, can be calculated, in principle, using:

$$Q = A_2 \times V_2 \tag{4.8}$$

The losses generally changed from point to point along a path and are controlled by surface conditions, flow path geometry, and local Reynolds number. Some losses may be proportional to the first power of the velocity, as in laminar channel flow, while others may be proportional to the square of local velocity, as in turbulent channel flow or separated flow. Allowing for both laminar and turbulent types of losses in Equation 4.7, the exit velocity is related to pressure difference by;

$$V_2^{\ 2} + e_l V_2 + e_t V_2^{\ 2} = 2\left[\frac{p_1 - p_2}{\rho}\right] \tag{4.9}$$

where e_l is the a sum of the laminar loss coefficients and e_t is the sum of the turbulent loss coefficients. Equation 4.9 shows that the leakage velocity is proportional to the n th power of the pressure differential, with n approaching 1/2 when $e_t >> e_l$ and n approaching 1 when $e_l >> (1 + e_t)$. Equation 4.8 can then be used to show that the leakage flow rate, Q, is proportional to that same power, n, of the pressure differential $(p_l - p_2)$ or Δp. Using c as proportionality constant, the leakage flow rate through a leakage area A is given by;

$$Q = c \times A \times (\Delta p)^n \tag{4.10}$$

As above, n can take on values from 1/2 to 1. For low leakage rates, where the flow is mostly laminar, the value of n would be close to 1. But as the leakage path flow resistance falls and/or the pressure difference becomes large, the leakage flow behaves more as turbulent flow and the exponent n drops to near 1/2.

Most duct leakage will have significant V^2 flow losses such as from the kinetic energy of the exit jet-the flow leaving the exit plane of the leakage path. Actual duct leakage therefore tends to have values of n closer to 0.5 than to 1.0. This is particularly true for ducts with large positive or negative internal pressures.

A convenient way to express leakage for a particular, i th, leakage site is to combine the unknown loss coefficient term with the unknown leakage area and to normalize the pressure difference. The normalized pressure difference or pressure ratio, $\Delta p^* = [\Delta p/\Delta p_{ref}]$, is used to preserve the form of the equation and the numerical coefficients *C* and n. The leakage for the i th site, Q_i, then becomes;

$$Q_i = C_i \times (\Delta p_i^*)^{n_i} \tag{4.11}$$

The leakage from a duct system would be the sum of the leakages at all "m" sites of the system. Since approximately the same pressure difference may exist at each site, or $\Delta p_i = \Delta p$, the total leakage can be expressed as;

$$Q_{total} = \sum_{i=1}^{m} Q_i = \sum_{i=1}^{m} \left[C_i \times (\Delta p_i^*)^{n_i} \right] \tag{4.12}$$

Carrying out the sum for the total leakage and dropping the subscript "total" yields;

$$Q = C \times (\Delta p^*)^n \tag{4.13}$$

where *C* is the overall leakage rate coefficient and n is the exponent for the duct system as a whole. The leakage rate coefficient, *C*, is the magnitude of the leakage at 250 Pa pressure differential, while n gives the increase leakage with an increase in pressure. Equation 4.13, called the *power law model*, was used to relate leakage rate data to the pressure difference driving the leakage without requiring knowledge of the actual leakage area [7,18].

Taking the logarithm of Equation 4.13 results in;

$$\log Q = n \times \log \Delta p^* + \log C \tag{4.14}$$

The value of n is the slope of the Q vs. Δp^* line on a log-log plot, while *C* is the Q intercept at $\Delta p^* = 1$. This model was used to present and interpret the measured leakage rates for the various test ducts. The measured values of Q and Δp^* are presented on log-log coordinates. The values of *C* and n can then be compared easily between duct types as well as between specific leakage sites. The power law leakage model also provides a convenient method by which to predict the leakage of a duct system when reliable values for *C* and n are available. *C* and n values were calculated using *last-squares* *method* to get the best fit of the power law model to each test consisting of seven or more data points. According to last squares method, power law model equation becomes;

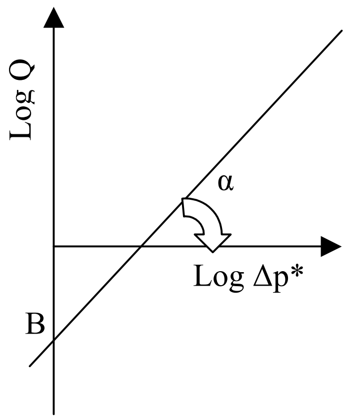
$$Y = nX + B \tag{4.15}$$

where:

Y equals log Q;

X equals log Δp^*;

B equals log *C*.



Y=0; X= (-B/n) meanwhile tan $\alpha = n$

X=0; Y= B meanwhile log $\Delta p^* = 0$; Q = C

$\Delta p^* = 1$; Q = C $\Rightarrow$ $\Delta p^* = 1$; $\Delta p = \Delta p_{ref}$

$\Delta p_{ref} = 250$ Pa.

A log-log plot of Q versus Δp^* will be a straight line if the data follow the power law model and the exponent n does not change with Δp. In some cases the expected straight line is concave downward, particularly at low-pressure differences. The downward bending of the log-log plots at low Δp likely results from a reduction in turbulence and a more laminar flow as the mean velocity decreases. The value of n would increase from a value of just more than 1/2 for the more turbulent leakage flow toward 1 for a laminar flow type.

Chapter 5

TEST SYSTEM and PROCEDURE

5.1. Experimental Apparatus

The leakage rates for a test duct were determined by measuring the makeup air required to maintain the duct at a constant, specified internal pressure. The internal duct pressure and the makeup flow rate were measured over a range of pressures between 400Pa and 1500Pa.

The leakage measurement system used was produced according to Smacna standards as shown in Figure 5.2 [13]. The system had a radial fan with variable speed control to supply makeup air. The output of the fan was manifolded into 200 mm diameter pipe with an adaptor piece. The variable speed control unit was used to obtain a fine adjustment of airflow into the test system. The straightener was used to get laminar flow on cross section area of measured air velocity. The straightener was designed with AMCA standard nozzle specifications as shown in Figure 5.1.

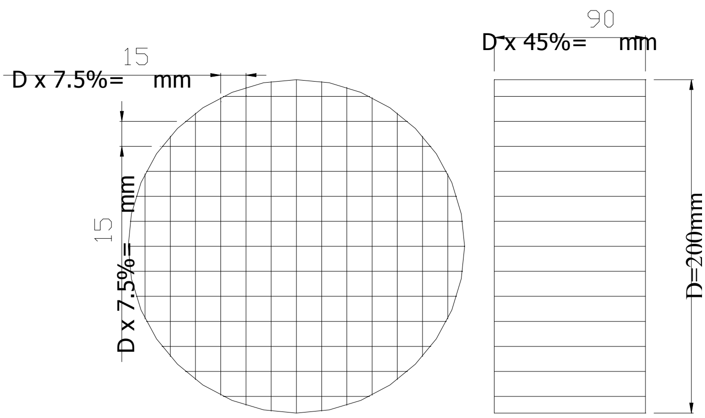


Figure 5.1 AMCA Standard Nozzle

The digital anemometer was connected to the test apparatus and used to measure the makeup airflow. The anemometer size was selected for the flow rate range needed for a test. The manometer was used to measure the pressure drop through the test duct.

The end caps were used at the end of test duct section and sealed onto the test duct section. The test unit was sealed completely. This sealed unit was leak-checked to ensure that leakage at the end caps and connecting pipe, plus the tape seal elsewhere, was less than 1% of the expected test system leakage. Therefore this value was ignored when reporting the test duct leakage.

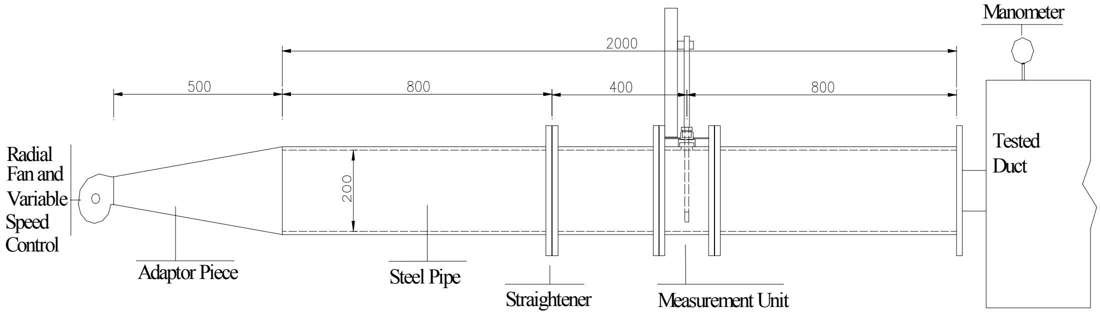


Figure 5.2 Experimental Apparatus

Working under the technical oversight of Eurovent and Smacna Standards, a laboratory duct leakage measurement system was developed and applied to measure total leakage rates and leakage of joints and seams and also to determine leakage classes for the products. The sheet metal ducts shown in Table5.1 were tested.

Table 5.1 The tested sheet metal ducts

Duct Size; Length	Seam Type	Joint Type
Ø300mm; 5m.	Spiral Lock	A single duct; No joint
Ø1000mm; 5m.	Spiral Lock	A single duct; No joint
300x250mm; 4.8m.	Pittsburgh Lock	Flanged joint in 1.2m. Sections
1000x500mm; 4.8m.	Pittsburgh Lock	Flanged joint in 1.2m. Sections
Ø300mm; 5m.	Spiral Lock	Beaded Slip Joints in 1.25m. Sections
Ø630mm; 3m.	Spiral Lock	Beaded Slip Joints in 1m. Sections
300x200mm; 4.8m.	Pittsburgh Lock	Flanged joint in 1.2m. Sections
500x300mm; 4.8m.	Pittsburgh Lock	Flanged joint in 1.2m. Sections
300x200mm; 4.8m.	Pittsburgh Lock	Drive Slip joint in 1.2m. Sections
500x300mm; 4.8m.	Pittsburgh Lock	Drive Slip joint in 1.2m. Sections
System in different diameters	Spiral Lock	Beaded Slip Joints in 8 Sections

5.1.1. Test System for a Single Duct

Spiral lock seam was used for circular duct production. This kind of seam is suitable for circular duct manufactured in a factory and airtightness is accepted level in all pressure classes. The seam sites were not sealed with a mastic or gasket during manufacturing the tested ducts. The spiral lock seam ducts were produced at 5 m lengths. The end caps were sealed at the beginning and end of the test duct section. The connection piece and round flange were used for the assembly of duct and test system. The spiral lock seam duct was in suspense at two points. The muff was welded on the duct for the assembly of the manometer.

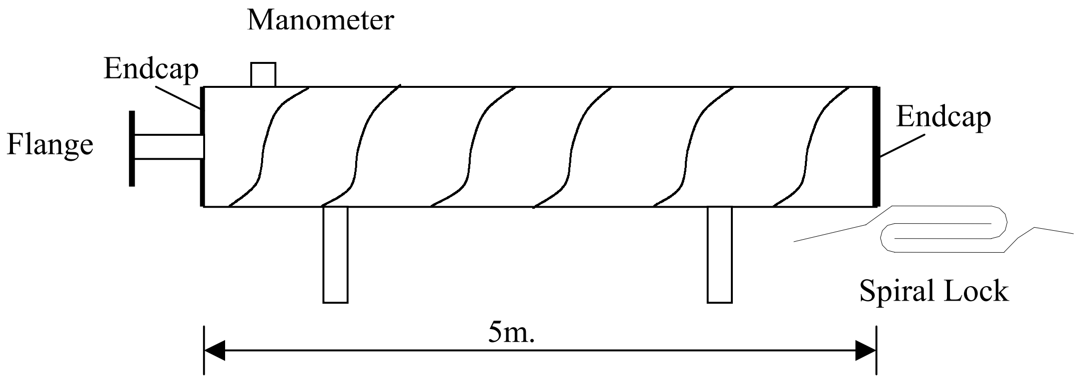


Figure 5.3 Spiral Lock Seam Test Duct Assembly

Pittsburgh lock seam was used for rectangular duct production. The seam sites were not sealed with a mastic or gasket during manufacturing the tested ducts. Pittsburgh lock seam ducts were produced in 1.2 m lengths and were connected to each other with flange and gasket. The corners of the rectangular duct were sealed with mastic. The end caps were sealed at the beginning and end of the test duct section. The connection piece and round flange were used for the assembly of duct and test system. Pittsburgh lock seam duct were in suspense at two points. The muff was welded on the duct for the assembly of the manometer.

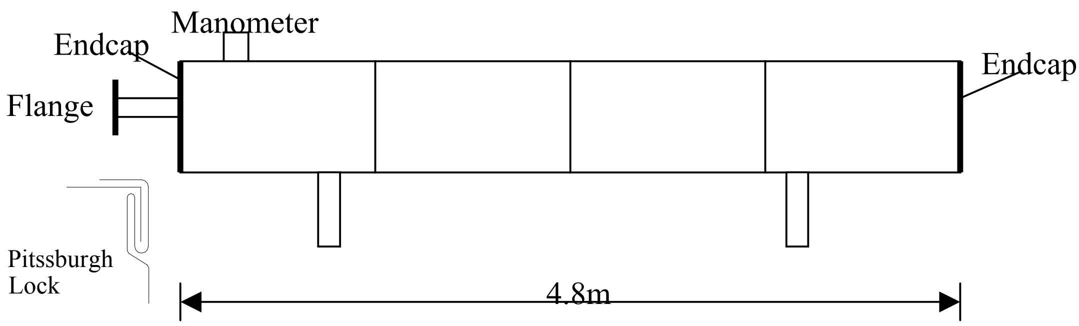


Figure 5.4 Pittsburgh Lock Seam Test Duct Assembly

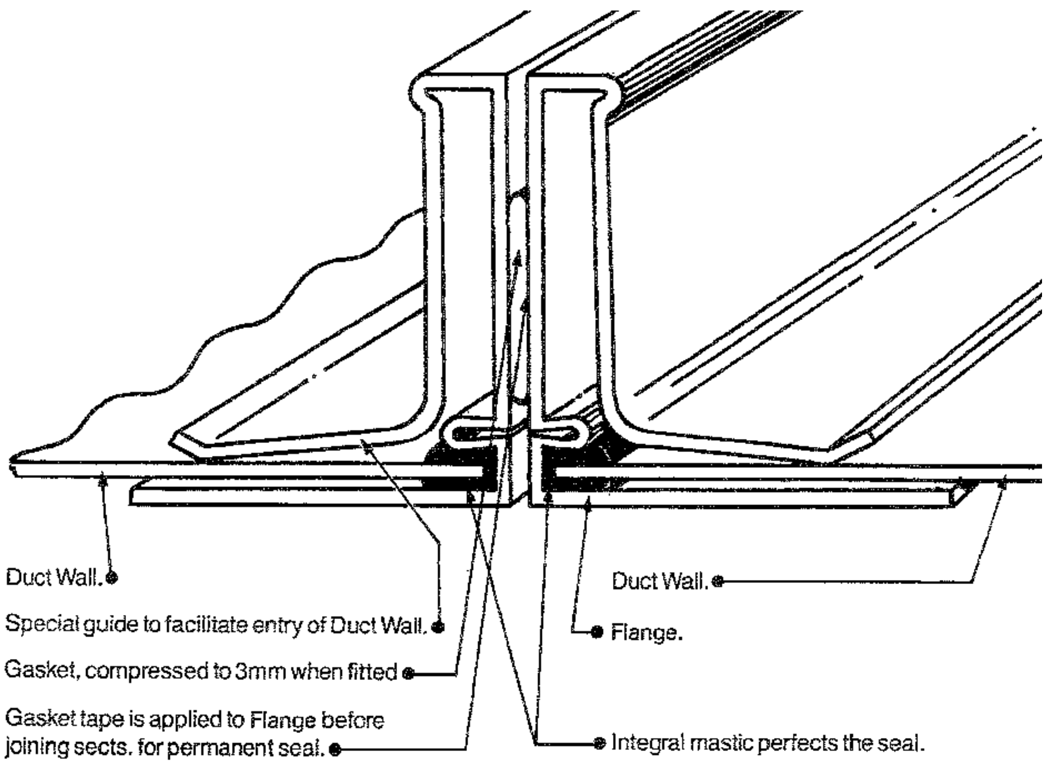


Figure 5.5 Flange and Duct Assembly [19]

The flanged connection type were used for rectangular duct testing. The air ducts which use flanged connection system minimizes loss of energy.

5.1.2. Test System for a Branched Duct System

Spiral lock seam was used for circular duct production, whereas, Pittsburgh lock seam was used for rectangular duct production. Spiral lock seam sites were not sealed with a mastic or gasket. The leakage rates for individual sites were determined by measuring leakage with and without sealing. For example, the seam leakage was determined by measuring the leakage with the joints sealed in rectangular ducts. The seam leakage could also be estimated by subtracting the measured joint leakage from the measured total leakage. Spiral lock seam ducts were produced at 1 m and 1.25 m lengths. Pittsburgh lock seam ducts were produced at 1.2 m lengths and connected to each other with flange and gasket.

The end caps were sealed at the beginning and end of the test duct section. The connection piece and round flange were used for the assembly of duct and test system. Pittsburgh lock and spiral lock seam duct were suspened at three points. The muff was welded on the duct for the assembly of the manometer.

Geometry of joints on rectangular ducts were chosen flanged joint with gasket and drive slip joint. Geometry of joints on circular ducts were chosen beaded slip coupler with three different gaskets as a Spiro, a Trelleborg and non sealed.

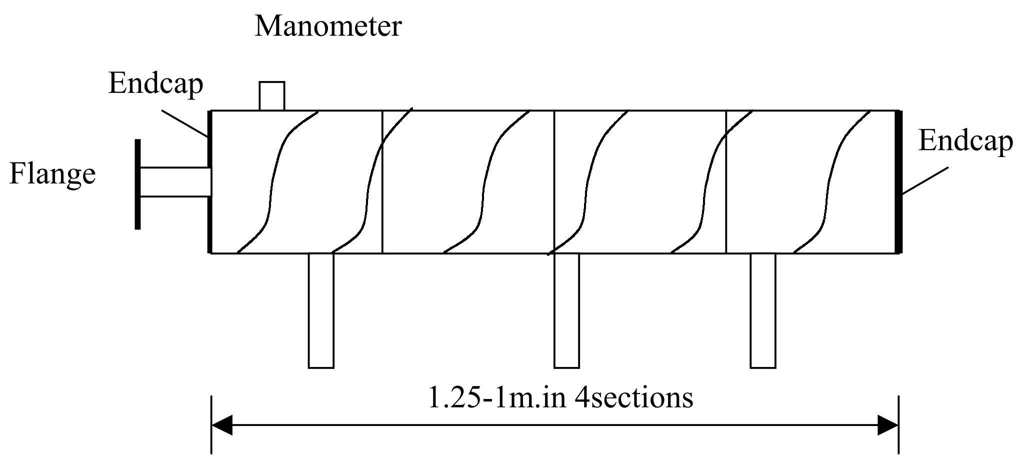


Figure 5.6 Test System on Circular Duct

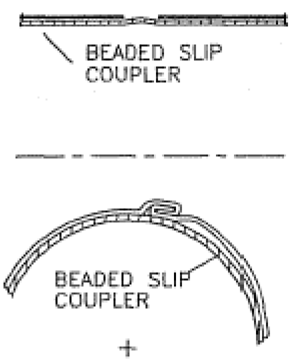


Figure 5.7 Geometry of joints on Circular Duct [7]

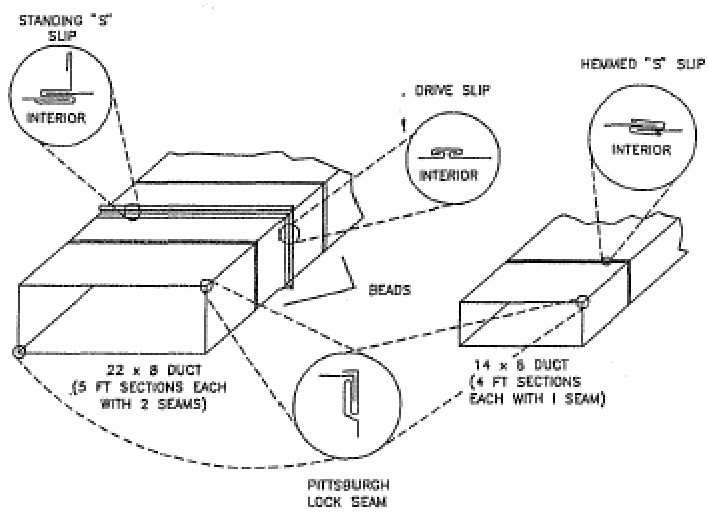


Figure 5.8 Geometry of joints on Rectangular Duct [7]

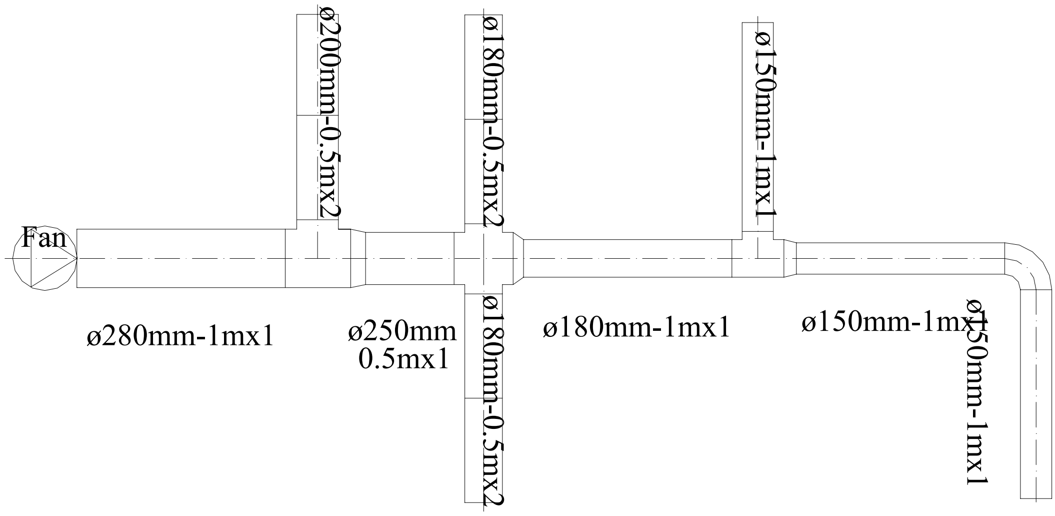


Figure 5.9 Test System for Distribution System.

Three different test systems were used; circular ducts in 1-1.25m sections, rectangular ducts 1.2m sections and in different diameters circular ducts distribution system. Circular duct distribution system is shown as above.

5.2. Test Procedure

The leakage measurement system is shown in Figure 5.2. Firstly, the duct was connected to the test apparatus and all joint surfaces were sealed. Then, the fan was run during fifteen minutes without any data saved to get stable airflow at required test pressure. The test pressure was adjustment with variable speed control unit to reach test pressures in the standard. All leakage measurement was made by increasing the internal pressure in the test component in several steps from 400Pa, 1000Pa, and 1200Pa to the maximum pressure 1500Pa. These settings were controlled with the manometer on the tested duct.

On the leakage measurement system, digital anemometer, 2D-lenghts away from the straightener, was used for measuring air velocity at each point. The velocity, $v>0$ for each point was resulted from air leakage through the tested duct. [20]. At each test pressure, the average air velocity was measured at eleven points both on horizontal and vertical axis. The velocity measurements were saved along five minutes at each point as shown in Figure 5.10.

All test duct materials and thickness were chosen for a comfortable installation and medium pressure class duct system. (Table 5.2)

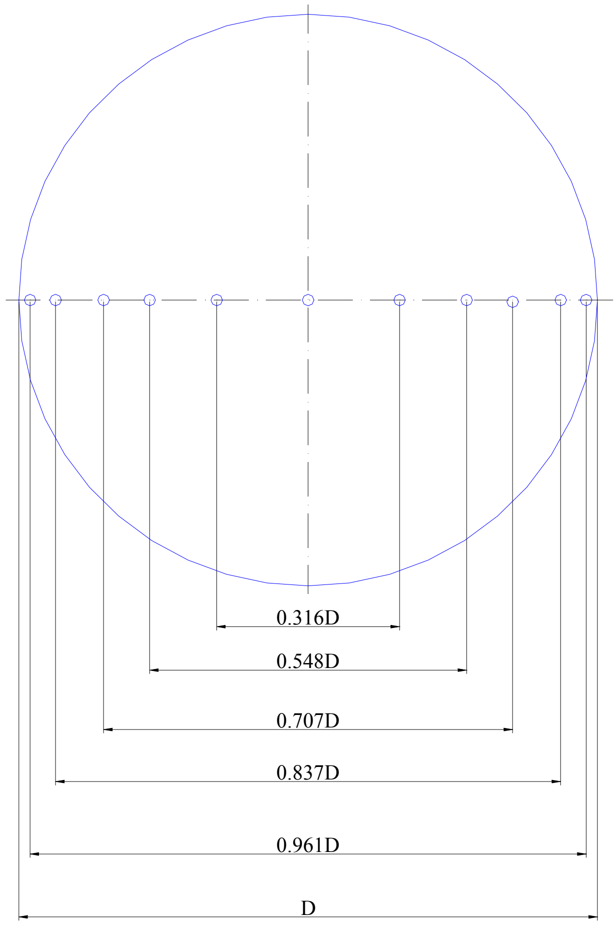


Figure 5.10 Measurement Points [20]

Table 5.2 Physicals Characteristics for Test Ducts

	Dimensions (mm)	Thickness (mm)	Length (m)	Surface Area (m^2)
Circular Single Ducts	Ø 300	0.65	5	4.71
	Ø 1000	1.05	5	15.70
Rectangular Single Ducts	300 x 250	0.55	4.8	5.28
	1000 x 500	0.75	4.8	14.4
Circular Beaded Slip Joint Ducts	Ø 300	0.65	5	4.71
	Ø 630	0.85	4	7.92
Rectangular Flanged and Drive Slip Joint Ducts	300 x 200	0.55	4.8	4.8
	500 x 300	0.55	4.8	7.68
Distribution System	150…280	0.55…0.75	-	7.14

Single duct leakage calculations were based on Eurovent Standard. But, duct leakage calculation for air distribution system with was based on Power Law Model [7,21]. In this study, leakage measurements were made on different types of duct and duct system by using a test apparatus based on TSE and Smacna Standards.

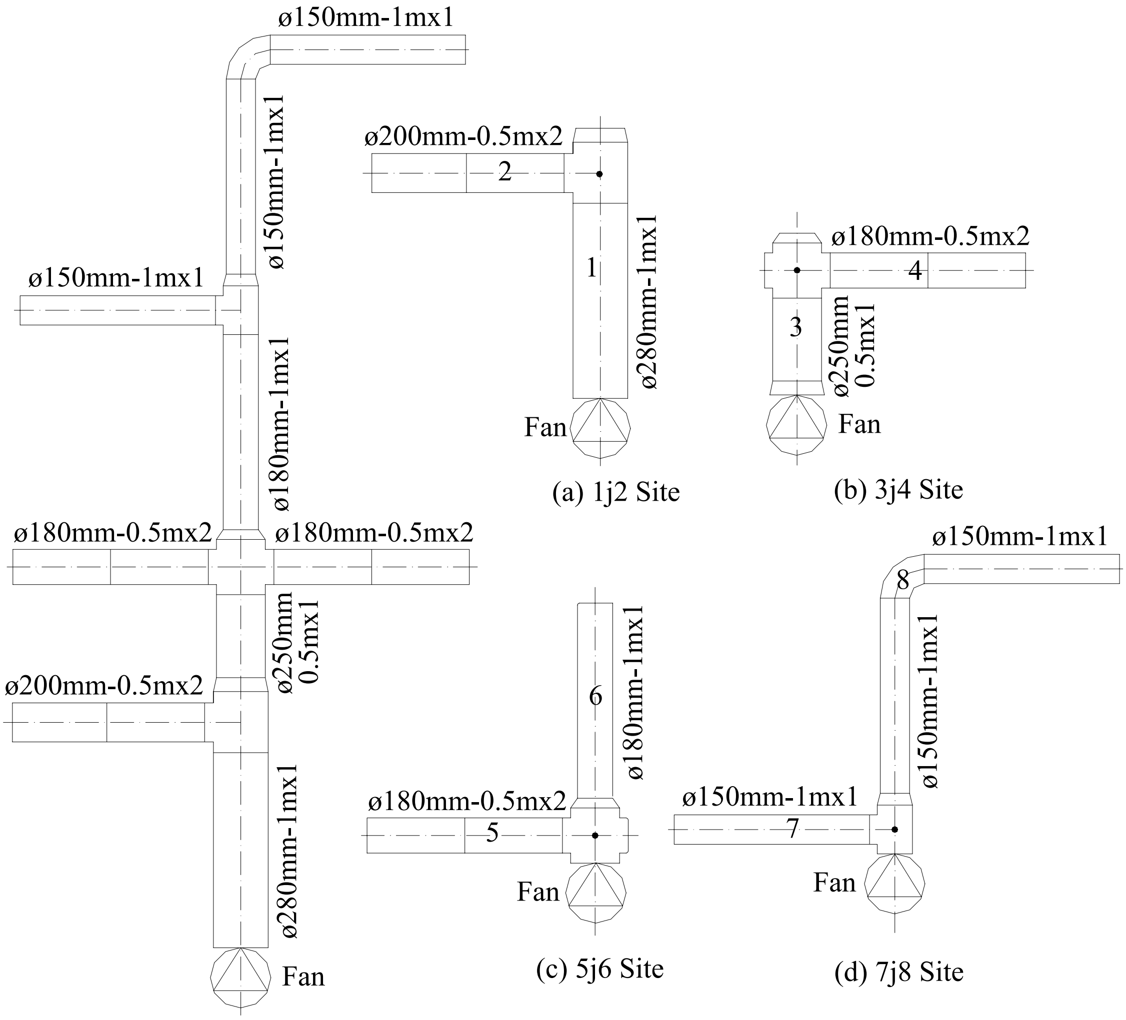


Figure 5.11 Test Procedure for Air Distribution System

The system was divided into four individual sites named 1j2, 3j4, 5j6, and 7j8 as shown above. All leakage measurements were made for five different sets. The end caps were used for duct connection parts and sealed with mastics.

Chapter 6

TEST RESULTS

All test ducts were produced by VENCO A.Ş. Test results showed that the leakage limits were under the allowable leakage limits in classification “C” for rectangular and circular ducts.

The tested ducts materials were chosen for a medium pressure class duct system. Therefore, test results under 1200Pa and 1500Pa test pressures (for High Pressure Duct System) had small difference between allowable leakage limits and calculated leakage limits. However, under 400Pa, 1000Pa. test pressures (for Medium Pressure Duct System), there were remarkable difference between allowable leakage limits and calculated leakage limits.

6.1. Test Results for Single Ducts

The leakage limits and leakage classes for ø300mm and ø1000mm circular ducts are seen in the Figures 6.1-6.2 shown below. All test leakage limits for circular ducts were under the C-Class allowable leakage limits.

The leakage limits and leakage classes for 300x250mm and 1000x500mm rectangular ducts are seen in the Figures 6.3-6.4 shown below. All test leakage limits for circular ducts were under the C-Class allowable leakage limits.

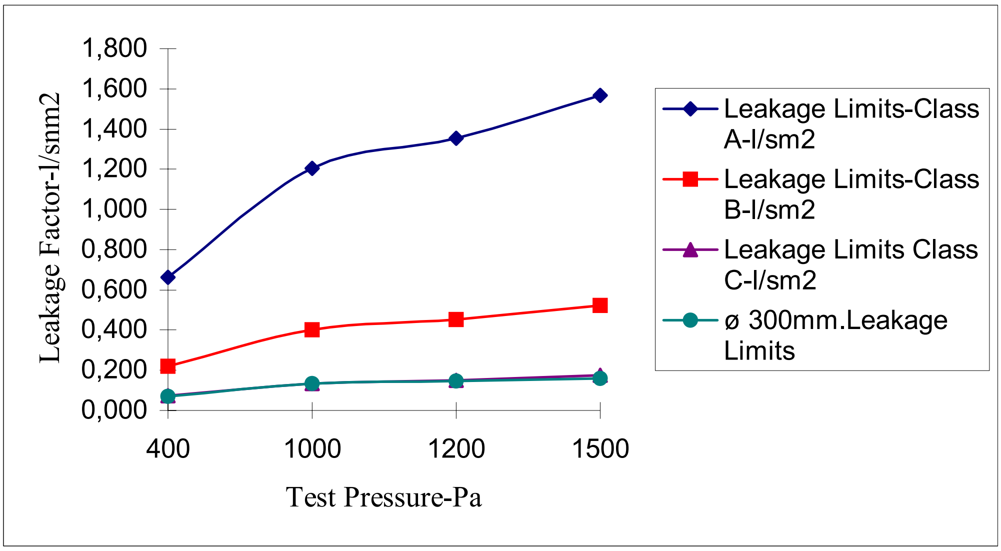


Figure 6.1 Spiral Lock Seamed Duct Leakage Limits (ø300mm)

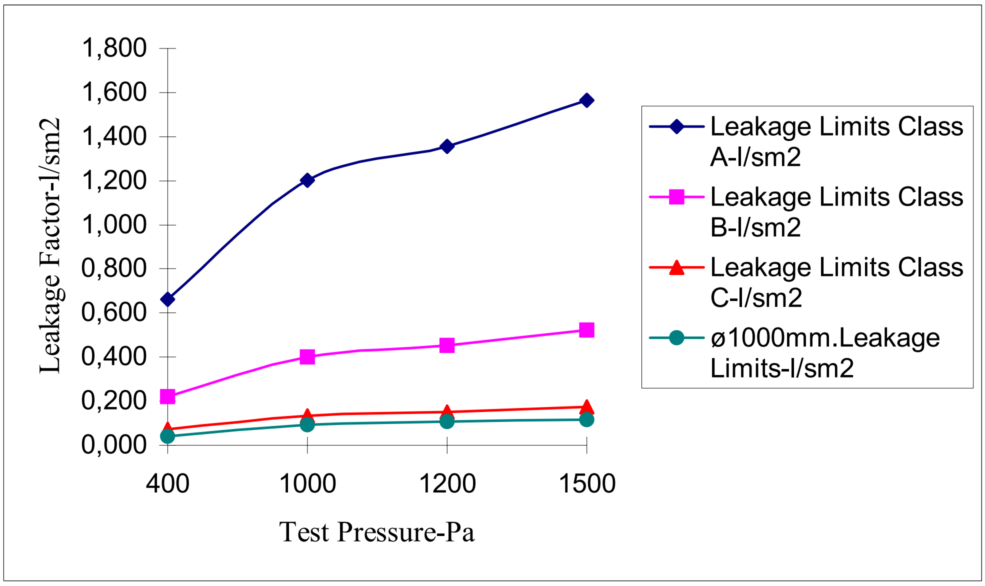


Figure 6.2 Spiral Lock Seamed Duct Leakage Limits (ø1000mm)

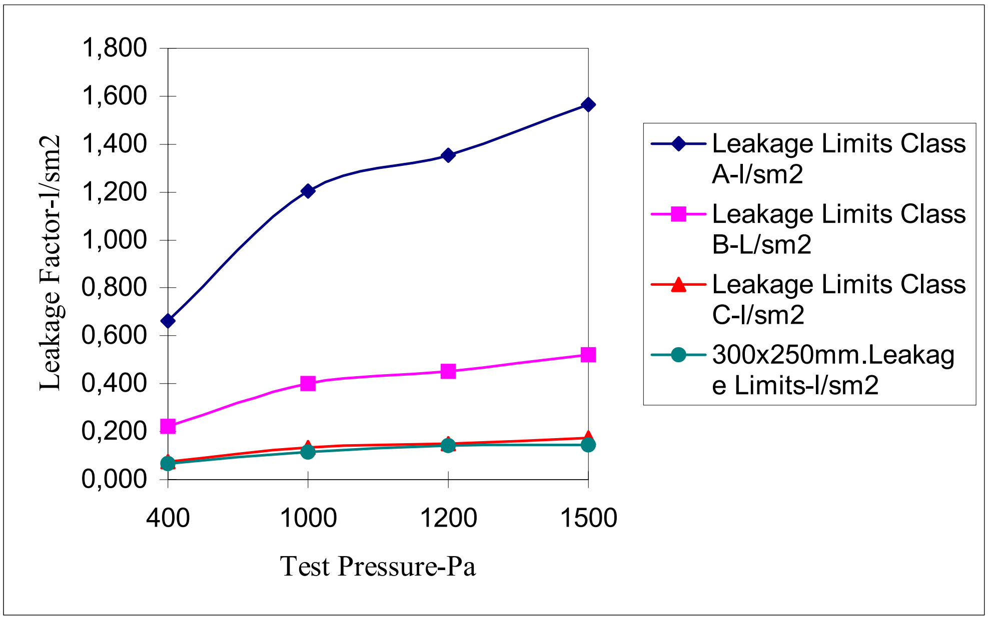


Figure 6.3 Pittsburgh Lock Seamed Rectangular Duct Leakage Limits (300x250mm)

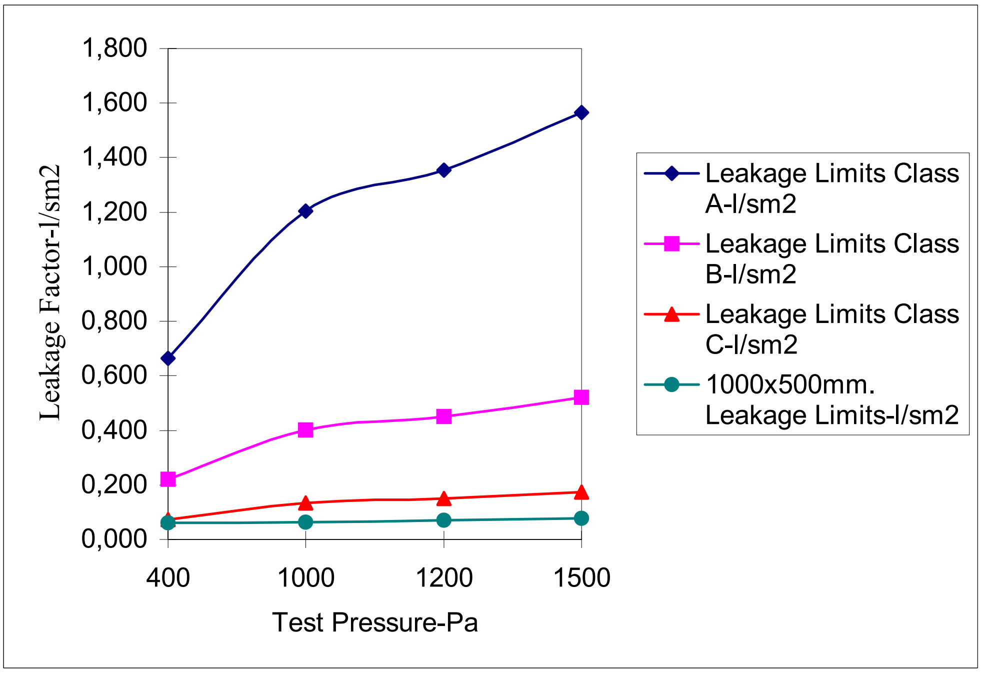


Figure 6.4 Pittsburgh Lock Seamed Rectangular Duct Leakage Limits (1000x500mm)

The test leakage limits for both rectangular and circular ducts are shown in the figure as below.

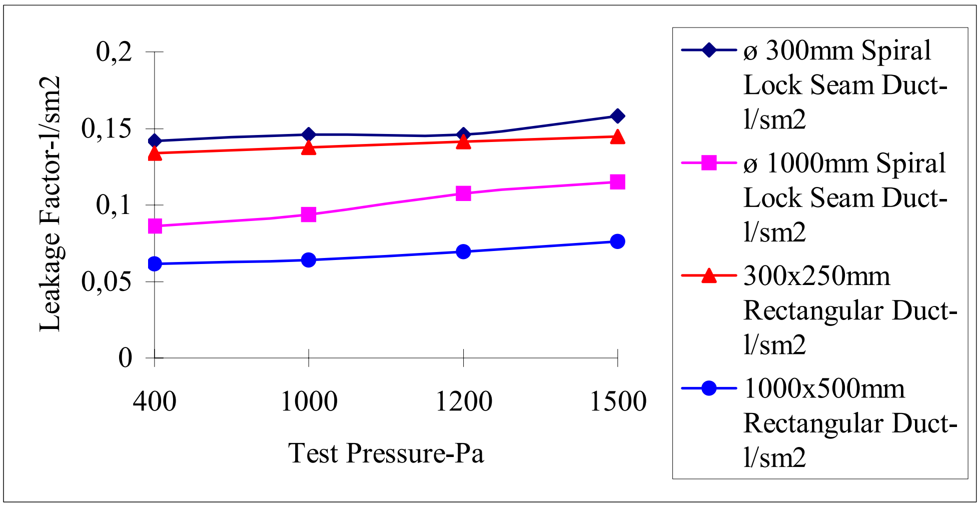


Figure 6.5 Rectangular and Circular Duct Leakage Limits

Comparing rectangular and circular ducts both have the same per unit surface area; the leakage from ø300mm circular duct was more than the leakage from 300x250mm rectangular duct as shown in Figure 6.5, because the length of seam for circular duct on the same surface area was longer than for rectangular duct. Furthermore, when the length of spiral lock seam corresponding to per unit surface area was 5.5 times longer than the length of Pittsburgh lock seam, the leakage from circular ducts was only 15% more than rectangular duct (Table 6.1). However, comparing rectangular and circular ducts both had the same length of seam and surface area; the leakage from circular ducts was 80% less than rectangular ducts.

Table 6.1 Comparing Air Leakages

Dimensions (mm)	Leakage Values at 1500Pa Test Pressure (l/sm2)	The length of seam on unit surface area (m)	Leakage Values for 1m length seam (l/sm2)
Ø 300	0.159	8.34	0.019
Ø 1000	0.115	8.34	0.014
300x250	0.145	1.53	0.095
1000x500	0.076	0.96	0.079

The air leakage, from ducts, with the same lock seam type, decreases whereas the surface area increases. Because, in rectangular ducts, surface area increases while the length of the seam, corresponding to unit surface area, decreases. However, in circular ducts, the length of seam does not change with unit surface area.

Finally, air duct systems are not leakage free except very special application such as transportation of very dangerous gasses. That's why, when the duct system is designed, the leakage class should be chosen and then ducts should be produced and controlled.

6.2. Test Results for Branched Duct System

Six different test duct types are listed in Table 6.2. Tables A.1, A.2, A.3 list the results of the individual tests for a ø300mm spiral lock seam duct with a beaded slip joint. Tables A.4, A.5, A.6 list the results of individual tests for ø630mm spiral lock seam duct with a beaded slip joint, and Tables A.7, A.8 and Tables A.9, A10 list those for the 300x200mm and 500x300mm Pittsburgh lock seam with flanged and drive slip joint as a rectangular duct, respectively. The *C* and n values are shown in Tables A.1.2.3…10. These values were calculated using the least-squares method to get the best fit of the power law model to each test consisting of eleven data points.

The leakage rate coefficient (*C*) and exponent n summarized in the first two data columns of Table 6.2 are for the complete test unit-two duct sections and the connecting joint, This was the basic test assembly used in these measurements. The next pair of data columns in Table 6.2 are for joint leakage only and the third pair of data columns are for seam leakage only. The values shown are the average of the best- fit values for all the tests.

The variation of *C* and n from sample to sample indicates that changes occurred in the size of the flow area of the leakage paths, in the nature of the flow, or in both. The cross-sectional dimensions of tile leakage path were so small that size changes from sample to sample were not visually apparent.

Table 6.2 Summaries of Duct Leakage Coefficients C and Exponents n

DUCT ASSEMBLY	Complete Test Unit (Two Sections&One Joint)			Joint Leakage (One Joint)			Seam Leakage (Two Duct Sections)		
	C		n	C		n	C		n
	cfm	m3/h	-	cfm	m3/h	-	cfm	m3/h	-
ø 300mm.Spiral lock-seam& Beaded Slip Joint.1.25m Sections	1.11	1.89	0.63	0.45	0.77	0.63	0.06	0.10	0.62
ø 630mm.Spiral lock-seam& Beaded Slip Joint.1m Sections	1.54	2.62	0.70	0.63	1.07	0.70	0.06	0.10	0.77
300x200mm.Pitssburgh Lock Seam Duct&Flanged Joints in 1.2m section	1.31	2.22	0.65	0.60	1.02	0.64	0.10	0.17	0.64
300x200mm.Pitssburgh Lock Seam Duct&Drive Slip Joints in 1.2m section	1.79	3.05	0.55	1.02	1.73	0.53	0.45	0.76	0.54
500x300mm.Pitssburgh Lock Seam Duct&Flanged Joints in 1.2m section	1.14	1.94	0.66	0.55	0.94	0.64	0.14	0.24	0.55
500x300mm.Pitssburgh Lock Seam Duct&Drive Slip Joints in 1.2m section	1.66	2.82	0.52	1.00	1.70	0.52	0.30	0.51	0.52

6.2.1. Test Results for Round Duct (300mm)

The two data sets plotted are the maximum and minimum values from the three tests of a given test configuration as listed in Table A.1, A.2 and A.3. Leakage rates for the 300mm spiral lock duct with a beaded slip joint and for positive internal pressure are shown in Figure 6.6. The spread between the lines for the total leakage shows that the variation in leakage for the two samples of the complete unit is less than 15%. The range of *C* for joint-only leakage is slightly lower, just less than 20%, ranging from 0.55 to 0.6 (Table A.1). The range of *C* seam leakage is quite smaller than 10%.

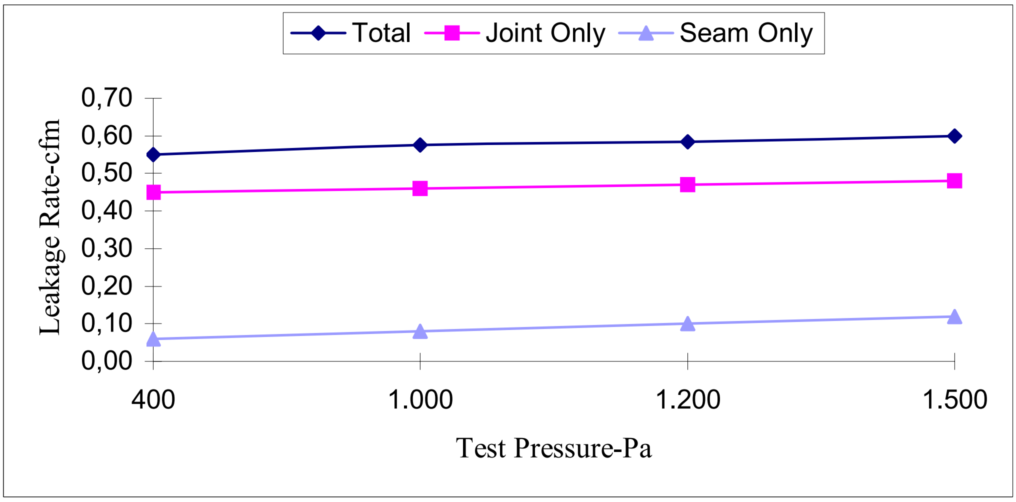


Figure 6.6 Leakage Measurements and Range of Data on Spiral Lock with Beaded Slip Joint Circular Duct (ø300mm)

Table 6.3 shows the results of Spiro and Trelleborg sealed, and unsealed leakage measurements. The leakage rate in Spiro sealed system is less than Trelleborg sealed system by 5%. The maximum leakage rate is measured for unsealed system. On the other hand, a joint leakage rate is 89% of total leakage at the beaded slip joint duct system with 300mm diameter. Furthermore, seam leakage is 11% of total leakage a spiral lock seam duct system with 300mm diameter.

Table 6.3 Power Law Constants C and n for 300mm. Diameter

DUCT ASSEMBLY	**SPIRO SEALED LEAKAGE (Four Sections & Three Joint)**			**TRELLEBORG SEALED LEAKAGE (Four Sections & Three Joint)**			**UNSEALED LEAKAGE (Four Sections & Three Joint)**		
	C - (leakage rate coefficient)		n (exponent)	C -(leakage rate coefficient)		n (exponent)	C- (leakage rate coefficient)		n (exponent)
	Cfm	m^3/h	-	cfm	m^3/h	-	Cfm	m^3/h	-
Ø 300mm.Spiral lock-seam& Beaded Slip Joint.1.25m Sections	1.11	1.89	0.63	1.17	1.99	0.61	1.76	3.00	0.27

DUCT ASSEMBLY	**TOTAL LEAKAGE**			**JOINT LEAKAGE**			**SEAM LEAKAGE**		
	Seam Unsealed; Joint Unsealed (Two Sections & One Joint)			Seam Sealed; Joint Unsealed (One Joint)			Seam Unsealed; Joint Sealed (Two Duct Sections)		
	C -(leakage rate coefficient)		n (exponent)	C - (leakage rate coefficient)		n (exponent)	C - (leakage rate coefficient)		n (exponent)
	Cfm	m^3/h	-	cfm	m^3/h	-	Cfm	m^3/h	-
ø 300mm.Spiral lock-seam& Beaded Slip Joint.1.25m Sections	0.57	0.98	0.42	0.45	0.77	0.63	0.06	0.10	0.60
Percent of Total Leakage				89%			11%		

6.2.2. Test Results for Round Duct (630mm)

Leakage rate shows a large variation for the beaded slip joint with 630mm diameter as shown in Figure 6.7 and Tables A.4, A.5, A.6. The values give maximum, minimum and average data sets for test ducts with Spiro sealed, Trelleborg sealed and unsealed beaded slip joints. For example, 1j2j3j4(complete system) with *C*=1.70, had twice the amount of leakage of the 1j2 and 2j3 sites (*C*=0,8) as seen in Table A.6. This situation is result of fittings locations. Furthermore, *C* values are very different in unsealed, Spiro sealed and Trelleborg sealed tests. Therefore appropriate value of *C* and n should be chosen in predicting leakage throughout duct systems.

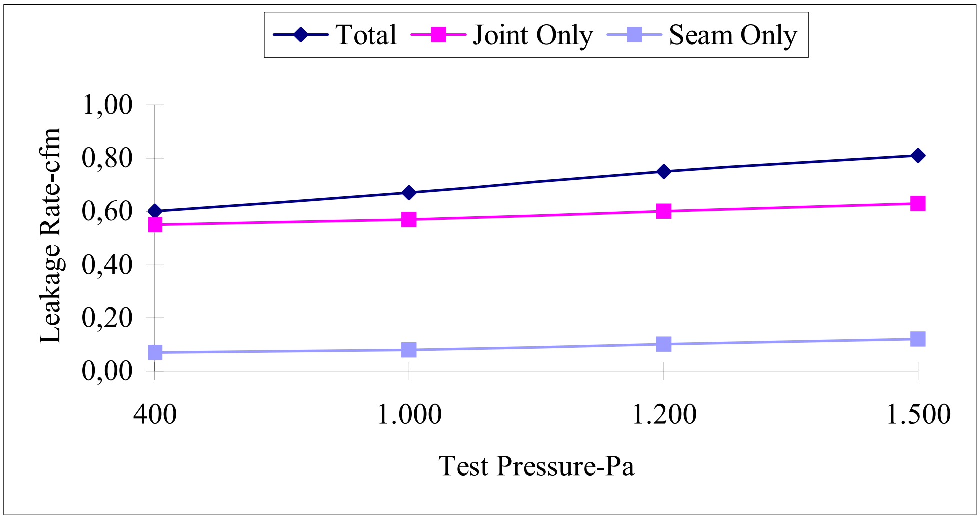


Figure 6.7 Leakage Measurements and Range of Data on Spiral Lock with Beaded Slip Joint Circular Duct (ø630mm)

Table 6.4 shows the results of Spiro and Trelleborg sealed, and unsealed leakage measurements. The leakage rate in Spiro sealed system is less than Trelleborg sealed system by 5%. The maximum leakage rate is measured for unsealed system. On the other hand, a joint leakage rate is 92% of total leakage at the beaded slip joint duct system with 630mm diameter. Furthermore, seam leakage is 8% of total leakage at the spiral lock seam duct system with 630mm diameter.

Table 6.4 Power Law Constants C and n for 630mm. Diameter

DUCT ASSEMBLY	**SPIRO SEALED LEAKAGE (Four Sections & Three Joint)**			**TRELLEBORG SEALED LEAKAGE (Four Sections & Three Joint)**			**UNSEALED LEAKAGE (Four Sections & Three Joint)**		
	C - (leakage rate coefficient)		n (exponent)	C -(leakage rate coefficient)		n (exponent)	C- (leakage rate coefficient)		n (exponent)
	cfm	m^3/h	-	cfm	m^3/h	-	cfm	m^3/h	-
ø 630mm.Spiral lock-seam& Beaded Slip Joint.1m Sections	1.54	2.62	0.70	1.61	2.74	0.67	1.70	2.90	0.34

DUCT ASSEMBLY	**TOTAL LEAKAGE**			**JOINT LEAKAGE**			**SEAM LEAKAGE**		
	Seam Unsealed ; Joint Unsealed (Two Sections & One Joint)			Seam Sealed ; Joint Unsealed (One Joint)			Seam Unsealed ; Joint Sealed (Two Duct Sections)		
	C -(leakage rate coefficient)		n (exponent)	C - (leakage rate coefficient)		n (exponent)	C - (leakage rate coefficient)		n (exponent)
	cfm	m^3/h	-	cfm	m^3/h	-	cfm	m^3/h	-
ø 630mm.Spiral lock-seam& Beaded Slip Joint.1m Sections	0.81	1.37	0.31	0.63	1.07	0.70	0.06	0.10	0.77
Percent of Total Leakage				92%			8%		

6.2.3. Test Results for Rectangular Ducts

Sample measurements on the 300-mm by 200-mm duct are listed in Table 6.5, Table A.7, A.8 and one set of test results is plotted in Figure 6.8. The geometry of seam and joint is shown in Figure 5.5 and 5.8.

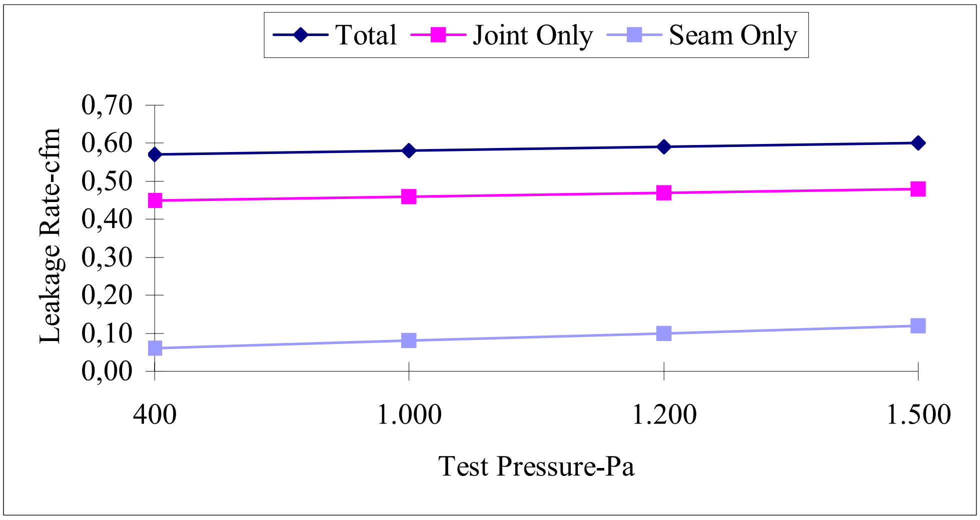


Figure 6.8 Leakage Measurements and Range of Data on Pittsburgh Lock with Flanged Joint Rectangular Duct (300x200mm)

The first part of Table 6.5 shows the results of flanged joints and drive slip joints leakage measurements. The leakage rate in flanged joint sealed system is less than drive slip joint system by 30%. The maximum leakage rate is measured for drive slip joint system. The other part of Table 6.5 shows joint and corner leakage rate, which is 86% of total leakage at the flanged joint duct system with 300x200mm dimensions. Furthermore, seam leakage is 14% of total leakage at the flanged joint duct system with 300x200mm dimensions. Duct systems with flanged and drive slip joints were produced by using Pittsburgh seam.

Table 6.5 Power Law Constants *C* and n for Rectangular Duct (300x200mm)

DUCT ASSEMBLY	**CORNERS and FLANGED JOINT LEAKAGE (Four Sections & Three Joint)**			**CORNERS and DRIVE SLIP JOINT LEAKAGE (Four Sections & Three Joint)**		
	C - (leakage rate coefficient)		n (exponent)	C -(leakage rate coefficient)		n (exponent)
	cfm	m^3/h	-	cfm	m^3/h	-
300x200mm.Pittsburgh Lock Seam Duct Joints in 1.2m section	1.31	2.22	0.65	1.79	3.05	0.52

DUCT ASSEMBLY	**SEAM LEAKAGE**			**CORNER&JOINT LEAKAGE**		
	Seam Unsealed; Joint Sealed (One Duct Sections)			Seam Sealed; Joint Unsealed (One Joint)		
	C -(leakage rate coefficient)		n (exponent)	C - (leakage rate coefficient)		n (exponent)
	cfm	m^3/h	-	cfm	m^3/h	-
300x200mm.Pittsburgh Lock Seam Duct Joints in 1.2m section	0.10	0.17	0.55	0.60	1.02	0.42
Percent of Total Leakage	14%			86%		

The first part of Table 6.6 and Tables A.7, A.8, A.9 shows the leakage measurements of duct systems with flanged and drive slip joints. The leakage rate in duct systems with flanged joint sealed system is less than drive slip joint system by 30%. The maximum leakage rate is measured for drive slip joint system. The other part of Table 6.6 shows joint and corner leakage rates, which is 80% of total leakage at the flanged joint duct system with 500x300mm dimensions. Furthermore, seam leakage is 20% of total leakage at the flanged joint duct system with 500x300mm dimensions. Duct systems with flanged and drive slip joints duct systems were produced using Pittsburgh seam.

Table 6.6 Power Law Constants *C* and n for Rectangular Duct (500x300mm)

DUCT ASSEMBLY	**CORNERS and FLANGED JOINT LEAKAGE (Four Sections & Three Joint)**			**CORNERS and DRIVE SLIP JOINT LEAKAGE (Four Sections & Three Joint)**		
	C - (leakage rate coefficient)		N (exponent)	C -(leakage rate coefficient)		n (exponent)
	cfm	m^3/h	-	cfm	m^3/h	-
500x300mm.Pitssburgh Lock Seam Duct in 1.2m section	1.14	1.94	0.66	1.66	2.82	0.67

DUCT ASSEMBLY	**SEAM LEAKAGE**			**CORNER&JOINT LEAKAGE**		
	Seam Unsealed; Joint Sealed (One Duct Sections)			Seam Sealed; Joint Unsealed (One Joint)		
	C -(leakage rate coefficient)		N (exponent)	C - (leakage rate coefficient)		n (exponent)
	cfm	m^3/h	-	cfm	m^3/h	-
500x300mm.Pitssburgh Lock Seam Duct in 1.2m section	0.14	0.24	0.55	0.55	0.94	0.62
Percent of Total Leakage	20%			80%		

Table 6.7 Average Site Leakages as Percent of Total Leakage

Leakage Site	**Rectangular Ducts with Flanged Joints**		**Spiral Lock Seam with Beaded Slip Joint**	
	500x300mm	300x200mm	Ø630mm	Ø300mm
Seam Leakage	20%	14%	8%	13%
Joint & Corners Leakage	80%	86%	92%	87%

Table 6.7 lists the average leakage values of the seams and joints as percentages of the total leakage. The average leakage measured in this study shows that seam leakage accounts from 14% to 20% of the total in the two rectangular ducts and from 8% to 13%

for the round ducts with Pittsburgh and Spiral lock seams. The spiral seam had almost no measurable leakage. These data show that the joints are the major leakage source of duct systems. Improvement in duct construction leading to duct systems with less leakage will need to focus on better joints.

The wide variations in leakage values from sample to sample indicate that field assembly of the joints and seams needs to be carefully done to achieve minimum leakage. Average workmanship produces the wide ranges in leakage rates. The drive slip joints used on rectangular ducts require greater skill and attention to achieve a good joint than the round duct joints tested. The rectangular joints are also found to be harder to than circular joints.

6.2.4. Test Results for Air Distribution System

Table 6.8 and Tables A.11, A.12, A.13 list the test results of a distribution duct system with different seal types. The sum of the measured leakage values for the individual sites was grater than the complete system.

Table 6.8 shows the results of Spiro, Trelleborg sealed and unsealed leakage measurements. The leakage rate in Spiro sealed system is less than Trelleborg sealed system by 5%. The maximum leakage rate is measured for unsealed system. On the other hand, a joint leakage rate is 78% of total leakage at the beaded slip joint duct system. Furthermore, seam leakage is 22% as a percent of total leakage from the spiral lock seam duct system.

Sealing is found to be effective in reducing duct leakage. The high leakage rates determined for joints and the large variation in leakage indicate that joints are the principal source of leakage. Special attention and careful work are needed when assembling duct joints to achieve low leakage rates. Development of new, lower leakage ducts will need to focus on improved joints.

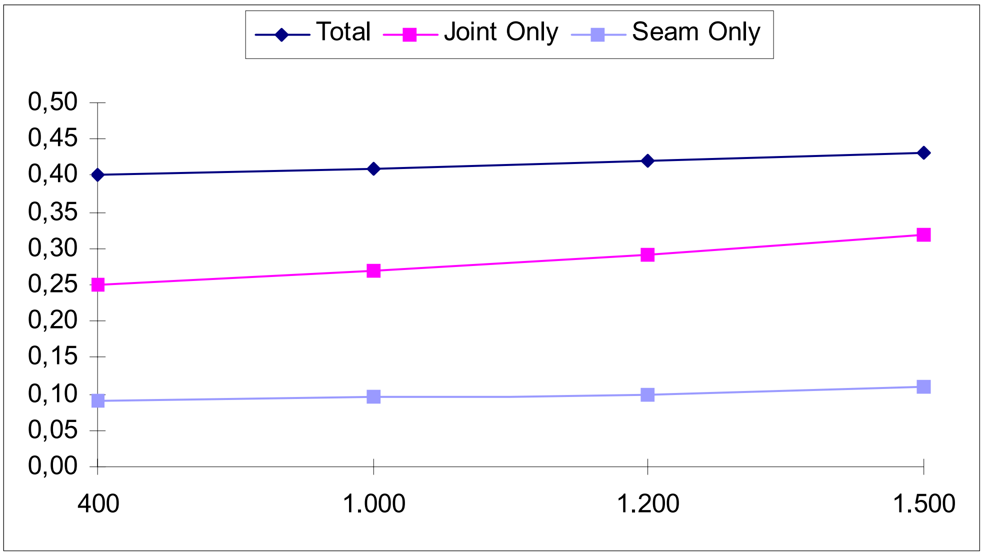


Figure 6.9 Leakage Measurements and Range of Data on Spiral Lock with Beaded Slip Joint Duct System at Positive Test Pressures

Leakage rates for the air distribution duct system with a beaded slip joint and for positive internal pressure are shown in Figure 6.9. The spread between the lines for the total leakage shows that the variation in leakage of the complete unit is less than 12%. The range of *C* for joint-only leakage is slightly lower, just less than 25%. The range of *C* seam leakage is quite smaller than 15%.

Table 6.8 Power Law Constants C and n for Distribution Duct System

DUCT ASSEMBLY	SPIRO SEALED LEAKAGE			TRELLEBORG SEALED LEAKAGE			UNSEALED LEAKAGE		
	C - (leakage rate coefficient)		n (exponent)	C -(leakage rate coefficient)		n (exponent)	C- (leakage rate coefficient)		n (exponent)
	Cfm	m^3/h	-	cfm	m^3/h	-	cfm	m^3/h	-
Spiral Lock Seam Branched Duct System with Beaded Slip Joints in different section	1.57	2.67	0.66	1.66	2.82	0.58	2.42	4.11	0.32
DUCT ASSEMBLY	TOTAL LEAKAGE			JOINT LEAKAGE			SEAM LEAKAGE		
	Seam Unsealed; Joint Unsealed			Seam Sealed; Joint Unsealed			Seam Unsealed; Joint Sealed		
	C -(leakage rate coefficient)		n (exponent)	C - (leakage rate coefficient)		n (exponent)	C - (leakage rate coefficient)		n (exponent)
	Cfm	m^3/h	-	cfm	m^3/h	-	cfm	m^3/h	-
Spiral Lock Seam Branched Duct System with Beaded Slip Joints in different section	0.41	0.70	0.37	0.28	0.47	0.66	0.08	0.14	0.65
Percent of Total Leakage				78%			22%		

Chapter 7

DISCUSSIONS and RECOMMENDATIONS

Leaks in air distribution systems are most often encountered at connections and at special components or accessories since these are particularly difficult to get airtight (e.g. heat exchanger). This is well known among the professionals but the solutions adopted to limit leakage are extremely different depending on the local customs, requirements, and control procedures. For instance where as factory fitted sealing gaskets are widely used, more conventional techniques (e.g. tape plus mastic) are frequently used. In these conditions, little attention is paid to duct leakage at installation and the airtightness of the systems is often poor.

Although there is an increasing concern for well-maintained systems, this need does not seem to be either clear or taken into account by the interested parties in most countries. This need is better identified in some countries where the impact of poorly maintained systems on IAQ performance is well understood. This is probably linked to the widespread use of balanced systems, with heat recovery, which encourage one to pay particular attention to the cleanliness of the supply ducts.

Another key problem lies in the gap between the prescriptions at the design stage and the actual performance on site. Significant efforts should be undertaken to convince people to use adequate techniques to guarantee good performance on site. Control at commissioning is also an important aspect.

7.1 Testing Ductwork According to prEN 12237

In this study test were performed for round and rectangular duct system. All tested ducts were product of the same company. Although prEN 12237 only requires a single point measurement procedure to determine the airtightness, the leakage flow rate was measured at several pressure stations at VENCO Company to be able to determine the flow exponent, *n*. The pressure in the ductwork was always in the region of 400 to 1500 Pa.

The following conclusions are made:

- In all cases the airtightness in the laboratory was better than the best class in prEN 12237 (which is Class C). This indicates that for laboratory tests an additional class (Class D) should be introduced;
- The flow exponent is in the region of 0.51 to 0.84. This indicates that the one-point measurement procedures can cause significant errors when the test pressure is significantly different from the reference pressure at which the leakage flow rate is calculated. Therefore, the application of a multi-point measurement procedure should be considered in prEN 12237;
- Performing the tests in under pressure always leads to the best result from the point of airtightness. This is probably caused by the fact that seam and joint openings are easily detected.

7.2. Suggested Design Methods for Ductwork Airtightness

The construction and installation of duct systems are two key aspects that have a major impact on ductwork airtightness. This chapter looks at today's technologies that may be used to limit duct leakage. It includes a short review of manufacturing process.

7.2.1. Ductwork Construction

Seams and joints should be suitably selected for the type of ductwork and leakage requirements. They should be compatible with the maintenance work (e.g. cleaning) to be performed on the system as well as the installers' skills and the time granted for site work. At the construction stage, the airtightness of individual components depends on the design (rectangular versus round, pressed versus segmented bends, flexible ducts, etc.) and assembly (seam type and welding quality). DW 144 gives a list of requirements to seal seams, laps, cross-joints and duct penetrations of different types. Also DW 143 states that it is important to make components with a good fit, and to use only enough sealant to make a satisfactory joint. A poor fit cannot be remedied by the use of more sealant.

Factory-fitted sealing devices (e.g. gaskets, clips) are available on the market. They appear to be efficient at reducing the installation time and give very satisfactory results in terms of airtightness. Some manufacturers include in their information brochures about the airtightness of individual components or the air distribution system between air handling unit and the terminal devices. As for air handling units and terminal devices themselves, very little information is available from the manufacturers although experience shows that they can be represent a significant source of leakage. Special care should be given to the fitting and sealing of maintenance panels and paths for electrical wires, fluid pipes, etc.

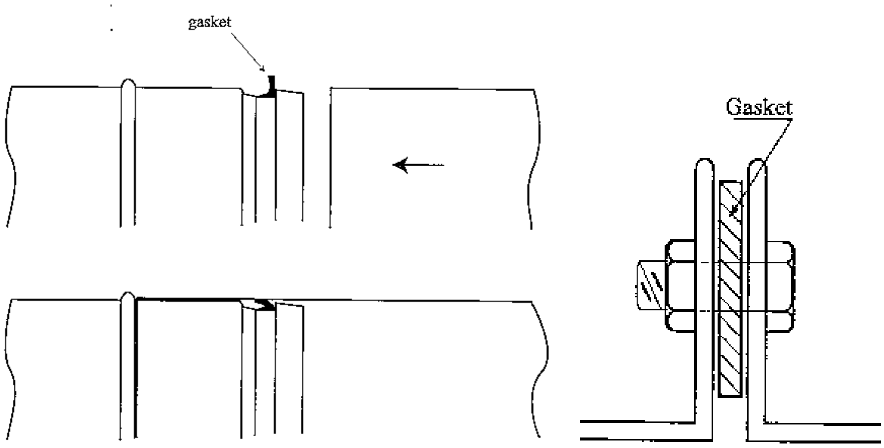


Figure 7.1 Pre-fitted sealing gaskets for circular ducts. Airtight rivets or plate-screws may be necessary to ensure the mechanical stability of the joint (left). Drive slips, fasteners, rivets or bolts are used to hold the pieces together [6]

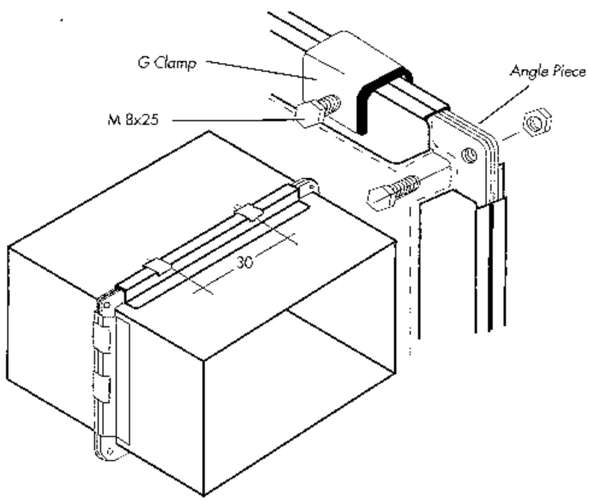


Figure 7.2 Flanged joints for rectangular ducts [6]

7.2.2. Ductwork Installation

The ductwork airtightness is also very sensitive to the workers' skills and sealing media when conventional sealing techniques are used. However, today's commercially available products considerably reduce the human factor. In addition to reduced installation time (about 25% according to the manufacturers), these products are cost-effective both on an investment and on Life Cycle Cost basis despite their initial higher purchase cost [6]. To obtain an airtight system, particular attention should be given the leakage.

- At seams and joints;
- Due to unnecessary holes or physical damage in duct runs;
- At air terminal devices;
- In the air handling unit.

The key advantage of duct components with factory fitted sealing devices (e.g. gaskets, clips) for joints lies in the ease and rapidity in obtaining airtight ducts. When quality products are used, the installation work mostly consists of ensuring the mechanical stability of the ductwork. Alternatively, when the components do not have pre-fitted sealing devices, additional work is needed at installation to avoid leakage at joints. Also, the installers should seal off unnecessary holes (for screws, rivets, measuring devices, etc.). Installation, inspection or rehabilitation work should be performed with caution so as to avoid physical damage to the ducts. Typically, significant leakage is found at the air terminal devices either because of poor connections to the ducts and against building materials, or because of internal cracks. Particular attention should be given to these parts. Finally, leakage in air handling units should be avoided using adequate sealing devices at maintenance panels and paths for electric wires, fluid pipes, etc. However, intentional holes are necessary for fire protection reasons (to cool the motor), they should not be sealed.

In general the use of quality-products with factory-fitted sealing devices does not eliminate completely on-site sealing. Nevertheless, they can spare the installers from doing much time-consuming and tedious tightening work. However, they are, in general, more expensive to purchase but the payback period decreases with increasing local costs of labour and energy. In fact, in many countries it is quite common to perform most of the sealing at installation although ‘pre-tight’ systems are available. These sealing methods could also be chosen for retrofitting leaky duct systems.

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APPENDIX A

TEST RESULTS and POWER LAW CONSTANTS

The averages of the best-fit values using least squares of C and n for all samples of all 6-test duct types are listed in tables. The C and n values in tables are also the best-fit values for the tests listed. These values were calculated using the least-squares method to get the best fit of the power law model to each test consisting of seven or more data measurement points.

Table A.1 Power Law Constants C and n for 300mm Diameter with Spiro Sealed Joints

Reference Pressure Difference (P_{ref})250Pa ; Ø300 Spiral Lock Seam Duct with Beaded Slip Joints in 1.25m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg $\Delta P^*=P/P_{ref}$	log Q-cfm $Q=(m^3/h)/1.69$	n-Values ....Turbulent Flow			<1	Air Leakage Coefficient-C-cfm	
1j2	2	1	0.004	400	0.452	0.204	-0.57259	***0.61***	***0.63***	***0.61***	0.65	0.20	0.45
	2	1	0.007	1000	0.791	0.602	-0.32956	***0.73***	**0.62**	***0.61***		0.47	
	2	1	0.008	1200	0.904	0.681	-0.27156	**0.53**	***0.63***	***0.73***		0.54	
	2	1	0.009	1500	1.017	0.778	-0.22041	**0.53**	**0.62**	***0.61***		0.60	
3j4	2	1	0.004	400	0.486	0.204	-0.54119	***0.53***	***0.57***	***0.56***	0.55	0.22	0.46
	2	1	0.007	1000	0.791	0.602	-0.32956	**0.73**	**0.62**	***0.53***		0.47	
	2	1	0.008	1200	0.904	0.681	-0.27156	***0.53***	***0.57***	**0.73**		0.54	
	2	1	0.009	1500	1.017	0.778	-0.22041	***0.53***	**0.62**	***0.56***		0.60	
1j2j3j4	4	3	0.010	400	1.074	0.204	-0.19693	***0.63***	***0.73***	***0.61***	0.63	0.47	1.11
	4	3	0.017	1000	1.908	0.602	0.05259	1.26	***0.57***	***0.63***		1.13	
	4	3	0.021	1200	2.402	0.681	0.15270	0.00	***0.73***	1.26		1.42	
	4	3	0.021	1500	2.402	0.778	0.15270	0.00	***0.57***	***0.61***		1.42	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.45	0.65
3j4	2	1	0.46	0.55
Average of 2 single joints samples			0.45	0.60
1j2j3j4	4	3	1.11	0.63
Average per Joint Unit			0.37	-
SERIES AVERAGE-Per 1 Joint			**0.41**	**0.62**

Table A.2 Power Law Constants C and n for 300mm Diameter with Trelleborg Sealed Joints

Reference Pressure Difference (P_{ref})250Pa ; Ø300 Spiral Lock Seam Duct with Beaded Slip Joints in 1.25m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg ΔP*=P/P_{ref}	log Q-cfm Q=(m^3/h)/1.69	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.003	400	0.339	0.204	-0.69753	***0.31***	***0.77***	***0.98***	0.69	0.15	0.40
	2	1	0.004	1000	0.452	0.602	-0.57259	3.07	2.49	***0.31***		0.27	
	2	1	0.007	1200	0.791	0.681	-0.32956	2.03	***0.77***	3.07		0.47	
	2	1	0.011	1500	1.243	0.778	-0.13326	2.03	2.49	***0.98***		0.74	
3j4	2	1	0.004	400	0.452	0.204	-0.57259	***0.24***	***0.74***	***0.77***	0.66	0.20	0.47
	2	1	0.005	1000	0.565	0.602	-0.47568	3.22	1.94	***0.24***		0.33	
	2	1	0.009	1200	1.017	0.681	-0.22041	***0.90***	***0.74***	3.22		0.60	
	2	1	0.011	1500	1.243	0.778	-0.13326	***0.90***	1.94	***0.77***		0.74	
1j2j3j4	4	3	0.010	400	1.130	0.204	-0.17465	***0.69***	***0.69***	***0.61***	0.61	0.50	1.17
	4	3	0.019	1000	2.120	0.602	0.09835	**0.69**	***0.45***	***0.69***		1.25	
	4	3	0.021	1200	2.402	0.681	0.15270	**0.26**	***0.69***	**0.69**		1.42	
	4	3	0.023	1500	2.543	0.778	0.17753	**0.26**	***0.45***	***0.61***		1.50	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.40	0.69
3j4	2	1	0.47	0.66
Average of 2 single joints samples			0.44	0.68
1j2j3j4	4	3	1.17	0.61
Average per Joint Unit			0.39	-
SERIES AVERAGE -Per 1 Joint			**0.41**	**0.64**

Table A.3 Power Law Constants C and n for 300mm Diameter with Unsealed Joints

Reference Pressure Difference (P_{ref})250Pa ; Ø300 Spiral Lock Seam Duct with Beaded Slip Joints in 1.25m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg $\Delta P^*=P/P_{ref}$	log Q-cfm $Q=(m^3/h)/1.69$	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.007	400	0.791	0.204	-0.32956	***0.15***	***0.23***	***0.27***	0.39	0.39	0.55
	2	1	0.008	1000	0.904	0.602	-0.27156	***0.65***	***0.55***	***0.15***		0.54	
	2	1	0.009	1200	1.017	0.681	-0.22041	***0.47***	***0.23***	***0.65***		0.60	
	2	1	0.010	1500	1.130	0.778	-0.17465	***0.47***	***0.55***	***0.27***		0.67	
3j4	2	1	0.006	400	0.678	0.204	-0.39650	***0.31***	***0.46***	***0.58***	0.45	0.32	0.60
	2	1	0.008	1000	0.904	0.602	-0.27156	1.22	1.20	***0.31***		0.54	
	2	1	0.010	1200	1.130	0.681	-0.17465	1.18	***0.46***	1.22		0.67	
	2	1	0.013	1500	1.470	0.778	-0.06071	1.18	1.20	***0.58***		0.87	
1j2j3j4	4	3	0.023	400	2.543	0.204	0.17753	***0.06***	***0.28***	***0.25***	0.27	1.32	1.76
	4	3	0.024	1000	2.685	0.602	0.20101	1.39	***0.68***	***0.06***		1.59	
	4	3	0.031	1200	3.462	0.681	0.31142	***0.09***	***0.28***	1.39		2.05	
	4	3	0.031	1500	3.533	0.778	0.32020	***0.09***	***0.68***	***0.25***		2.09	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.55	0.39
3j4	2	1	0.60	0.45
Average of 2 single joints samples			0.57	0.42
1j2j3j4	4	3	1.76	0.27
Average per Joint Unit			0.59	-
SERIES AVERAGE-Per 1 Joint			**0.58**	**0.35**

Table A.4 Power Law Constants C and n for 630mm Diameter with Spiro Sealed Joints

Reference Pressure Difference (P_{ref})250Pa ; Ø630 Spiral Lock Seam Duct with Beaded Slip Joints in 1m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg ΔP*=P/P_{ref}	log Q-cfm Q=(m^3/h)/1.69	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.005	400	0.565	0.204	-0.47568	***0.76***	***0.54***	***0.83***	0.71	0.24	0.63
	2	1	0.010	1000	1.130	0.602	-0.17465	-0.58	1.00	***0.76***		0.67	
	2	1	0.009	1200	1.017	0.681	-0.22041	2.29	***0.54***	-0.58		0.60	
	2	1	0.015	1500	1.696	0.778	0.00144	2.29	1.00	***0.83***		1.00	
3j4	2	1	0.004	400	0.452	0.204	-0.57259	1.29	***0.83***	***0.83***	0.83	0.18	0.63
	2	1	0.013	1000	1.470	0.602	-0.06071	-1.44	-0.20	1.29		0.87	
	2	1	0.010	1200	1.130	0.681	-0.17465	***0.82***	***0.83***	-1.44		0.67	
	2	1	0.012	1500	1.356	0.778	-0.09547	***0.82***	-0.20	***0.83***		0.80	
1j2j3j4	4	3	0.013	400	1.413	0.204	-0.07774	***0.81***	***0.65***	***0.69***	0.70	0.60	1.54
	4	3	0.026	1000	2.967	0.602	0.24447	-0.13	***0.43***	***0.81***		1.76	
	4	3	0.026	1200	2.897	0.681	0.23401	***0.89***	***0.65***	-0.13		1.71	
	4	3	0.031	1500	3.533	0.778	0.32020	***0.89***	***0.43***	***0.69***		2.09	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.63	0.71
3j4	2	1	0.63	0.83
Average of 2 single joints samples			0.63	0.77
1j2j3j4	4	3	1.54	0.70
Average per Joint Unit			0.51	-
SERIES AVERAGE (Per 1 Joint Unit)			**0.57**	**0.73**

Table A.5 Power Law Constants C and n for 630mm Diameter with Trelleborg Sealed Joints

Reference Pressure Difference (P_{ref})250Pa ; Ø630 Spiral Lock Seam Duct with Beaded Slip Joints in 1m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg $\Delta P^* = P/P_{ref}$	log Q-cfm $Q=(m^3/h)/1.69$	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.006	400	0.678	0.204	-0.39650	***0.56***	***0.46***	***0.64***	0.62	0.30	0.64
	2	1	0.010	1000	1.130	0.602	-0.17465	0.00	***0.83***	***0.56***		0.67	
	2	1	0.010	1200	1.130	0.681	-0.17465	1.51	***0.46***	0.00		0.67	
	2	1	0.014	1500	1.583	0.778	-0.02853	1.51	***0.83***	***0.64***		0.94	
3j4	2	1	0.004	400	0.452	0.204	-0.57259	1.37	1.07	1.00	0.64	0.20	0.75
	2	1	0.014	1000	1.583	0.602	-0.02853	-0.41	0.17	1.37		0.94	
	2	1	0.013	1200	1.470	0.681	-0.06071	***0.64***	1.07	-0.41		0.87	
	2	1	0.015	1500	1.696	0.778	0.00144	***0.64***	0.17	1.00		1.00	
1j2j3j4	4	3	0.014	400	1.554	0.204	-0.03635	***0.76***	***0.59***	***0.65***	0.67	0.67	1.61
	4	3	0.028	1000	3.109	0.602	0.26468	-0.26	***0.41***	***0.76***		1.84	
	4	3	0.026	1200	2.967	0.681	0.24447	**0.96**	***0.59***	-0.26		1.76	
	4	3	0.033	1500	3.674	0.778	0.33723	**0.96**	***0.41***	***0.65***		2.17	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.64	0.62
3j4	2	1	0.75	0.64
Average of 2 single joints samples			0.70	0.63
1j2j3j4	4	3	1.61	0.67
Average per Joint Unit			0.54	-
SERIES AVERAGE-Per 1 Joint			**0.62**	**0.65**

Table A.6 Power Law Constants C and n for 630mm Diameter with Unsealed Joints

Reference Pressure Difference (P_{ref})250Pa ; Ø630 Spiral Lock Seam Duct with Beaded Slip Joints in 1m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg $\Delta P^*=P/P_{ref}$	log Q-cfm $Q=(m^3/h)/1.69$	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.010	400	1.130	0.204	-0.17465	***0.10***	***0.31***	***0.31***	0.30	0.58	0.81
	2	1	0.011	1000	1.243	0.602	-0.13326	1.32	***0.76***	***0.10***		0.74	
	2	1	0.014	1200	1.583	0.681	-0.02853	***0.31***	***0.31***	1.32		0.94	
	2	1	0.015	1500	1.696	0.778	0.00144	***0.31***	***0.76***	***0.31***		1.00	
3j4	2	1	0.009	400	1.017	0.204	-0.22041	***0.11***	***0.46***	***0.39***	0.32	0.52	0.80
	2	1	0.010	1000	1.130	0.602	-0.17465	2.22	1.00	***0.11***		0.67	
	2	1	0.015	1200	1.696	0.681	0.00144	0.00	***0.46***	2.22		1.00	
	2	1	0.015	1500	1.696	0.778	0.00144	0.00	1.00	***0.39***		1.00	
1j2j3j4	4	3	0.023	400	2.543	0.204	0.17753	***0.06***	***0.19***	***0.25***	0.34	1.28	1.70
	4	3	0.024	1000	2.685	0.602	0.20101	**0.85**	***0.68***	***0.06***		1.59	
	4	3	0.028	1200	3.137	0.681	0.26861	***0.53***	***0.19***	**0.85**		1.86	
	4	3	0.031	1500	3.533	0.778	0.32020	***0.53***	***0.68***	***0.25***		2.09	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.81	0.30
3j4	2	1	0.80	0.32
Average of 2 single joints samples			0.81	0.31
1j2j3j4	4	3	1.70	0.34
Average per Joint Unit			0.57	-
SERIES AVERAGE-Per 1 Joint			**0.69**	**0.33**

Table A.7 Power Law Constants C and n for 300x200mm Rectangular Duct Flanged with Gasket Joints

Reference Pressure Difference (P_{ref})250Pa ; 300x200mm.Pittsburgh Lock Seam Duct with Flanged Joints in 1.2m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg ΔP*=P/P_{ref}	log Q-cfm Q=(m^3/h)/1.69	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.006	400	0.678	0.204	-0.39650	***0.44***	***0.70***	***0.69***	0.62	0.30	0.69
	2	1	0.009	1000	1.017	0.602	-0.22041	2.02	1.26	***0.44***		0.60	
	2	1	0.013	1200	1.470	0.681	-0.06071	***0.64***	***0.70***	2.02		0.87	
	2	1	0.015	1500	1.696	0.778	0.00144	***0.64***	1.26	***0.69***		1.00	
3j4	2	1	0.005	400	0.565	0.204	-0.47568	***0.76***	***0.63***	***0.66***	0.66	0.24	0.60
	2	1	0.010	1000	1.130	0.602	-0.17465	0.00	***0.45***	***0.76***		0.67	
	2	1	0.010	1200	1.130	0.681	-0.17465	***0.82***	***0.63***	0.00		0.67	
	2	1	0.012	1500	1.356	0.778	-0.09547	***0.82***	***0.45***	***0.66***		0.80	
1j2j3j4	4	3	0.011	400	1.272	0.204	-0.12350	***0.65***	***0.65***	***0.65***	0.65	0.56	1.31
	4	3	0.020	1000	2.303	0.602	0.13444	**0.66**	***0.65***	***0.65***		1.36	
	4	3	0.023	1200	2.600	0.681	0.18707	***0.63***	***0.65***	**0.66**		1.54	
	4	3	0.027	1500	2.996	0.778	0.24859	***0.63***	***0.65***	***0.65***		1.77	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.69	0.62
3j4	2	1	0.60	0.66
Average of 2 single joints samples			0.64	0.64
1j2j3j4	4	3	1.31	0.65
Average per Joint Unit			0.44	-
SERIES AVERAGE-Per 1 Joint			**0.54**	**0.64**

Table A.8 Power Law Constants C and n for 300x200mm Rectangular Duct Drive Slip Joints

Reference Pressure Difference (P_{ref})250Pa ; 300x200mm.Pitssburgh Lock Seam Duct with Drive Slip Joints in 1.2m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg $\Delta P^*=P/P_{ref}$	log Q-cfm $Q=(m^3/h)/1.69$	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.010	400	1.130	0.204	-0.17465	***0.10***	***0.31***	***0.31***	0.30	0.58	0.81
	2	1	0.011	1000	1.243	0.602	-0.13326	1.32	***0.76***	***0.10***		0.74	
	2	1	0.014	1200	1.583	0.681	-0.02853	***0.31***	***0.31***	1.32		0.94	
	2	1	0.015	1500	1.696	0.778	0.00144	***0.31***	***0.76***	***0.31***		1.00	
3j4	2	1	0.009	400	1.017	0.204	-0.22041	***0.11***	***0.46***	***0.39***	0.32	0.52	0.80
	2	1	0.010	1000	1.130	0.602	-0.17465	2.22	1.00	***0.11***		0.67	
	2	1	0.015	1200	1.696	0.681	0.00144	0.00	***0.46***	2.22		1.00	
	2	1	0.015	1500	1.696	0.778	0.00144	0.00	1.00	***0.39***		1.00	
1j2j3j4	4	3	0.019	400	2.120	0.204	0.09835	***0.42***	***0.43***	***0.47***	0.52	0.98	1.79
	4	3	0.028	1000	3.109	0.602	0.26468	**0.48**	***0.59***	***0.42***		1.84	
	4	3	0.030	1200	3.391	0.681	0.30247	***0.69***	***0.43***	**0.48**		2.01	
	4	3	0.035	1500	3.956	0.778	0.36941	***0.69***	***0.59***	***0.47***		2.34	

TEST SETUP			C-cfm	n
1j2	2	1	0.81	0.30
3j4	2	1	0.80	0.32
Average of 2 single joints samples			0.81	0.31
1j2j3j4	4	3	1.79	0.52
Average per Joint Unit			0.60	-
SERIES AVERAGE-Per 1 Joint			**0.70**	**0.42**

Table A.9 Power Law Constants C and n for 500x300mm Rectangular Duct Flanged with Gasket Joints

Reference Pressure Difference (P_{ref})250Pa ; 500x300mm.Pittsburgh Lock Seam Duct with Flanged Joints in 1.2m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg $\Delta P^* = P/P_{ref}$	log Q-cfm $Q = (m^3/h)/1.69$	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.004	400	0.452	0.204	-0.57259	***0.44***	***0.63***	***0.69***	0.59	0.20	0.45
	2	1	0.006	1000	0.678	0.602	-0.39650	1.58	1.26	***0.44***		0.40	
	2	1	0.008	1200	0.904	0.681	-0.27156	1.00	***0.63***	1.58		0.54	
	2	1	0.010	1500	1.130	0.778	-0.17465	1.00	1.26	***0.69***		0.67	
3j4	2	1	0.004	400	0.452	0.204	-0.57259	***0.61***	***0.51***	***0.77***	0.63	0.20	0.47
	2	1	0.007	1000	0.791	0.602	-0.32956	0.00	1.11	***0.61***		0.47	
	2	1	0.007	1200	0.791	0.681	-0.32956	2.03	***0.51***	0.00		0.47	
	2	1	0.011	1500	1.243	0.778	-0.13326	2.03	1.11	***0.77***		0.74	
1j2j3j4	4	3	0.010	400	1.130	0.204	-0.17465	***0.55***	***0.60***	***0.69***	0.66	0.49	1.14
	4	3	0.017	1000	1.879	0.602	0.04611	***0.80***	1.01	***0.55***		1.11	
	4	3	0.019	1200	2.176	0.681	0.10978	1.17	***0.60***	***0.80***		1.29	
	4	3	0.025	1500	2.826	0.778	0.22329	1.17	1.01	***0.69***		1.67	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.45	0.59
3j4	2	1	0.47	0.63
Average of 2 single joints samples			0.46	0.61
1j2j3j4	4	3	1.14	0.66
Average per Joint Unit			0.38	-
SERIES AVERAGE-Per 1 Joint			**0.42**	**0.64**

Table A.10 Power Law Constants C and n for 500x300mm Rectangular Duct Drive Slip Joints

Reference Pressure Difference (P_{ref})250Pa ; 500x300mm.Pitssburgh Lock Seam Duct with Drive Slip Joints in 1.2m section

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg $\Delta P^*=P/P_{ref}$	log Q-cfm $Q=(m^3/h)/1.69$	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.007	400	0.791	0.204	-0.32956	***0.39***	***0.63***	***0.67***	0.64	0.35	0.77
	2	1	0.010	1000	1.130	0.602	-0.17465	1.85	1.31	***0.39***		0.67	
	2	1	0.014	1200	1.583	0.681	-0.02853	***0.87***	***0.63***	1.85		0.94	
	2	1	0.017	1500	1.922	0.778	0.05579	***0.87***	1.31	***0.67***		1.14	
3j4	2	1	0.008	400	0.904	0.204	-0.27156	***0.44***	***0.37***	***0.52***	0.51	0.42	0.77
	2	1	0.012	1000	1.356	0.602	-0.09547	0.00	***0.71***	***0.44***		0.80	
	2	1	0.012	1200	1.356	0.681	-0.09547	1.29	***0.37***	0.00		0.80	
	2	1	0.016	1500	1.809	0.778	0.02947	1.29	***0.71***	***0.52***		1.07	
1j2j3j4	4	3	0.016	400	1.837	0.204	0.03620	***0.41***	***0.52***	***0.58***	0.67	0.79	1.66
	4	3	0.024	1000	2.685	0.602	0.20101	1.05	***0.96***	***0.41***		1.59	
	4	3	0.029	1200	3.250	0.681	0.28398	***0.88***	***0.52***	1.05		1.92	
	4	3	0.035	1500	3.956	0.778	0.36941	***0.88***	***0.96***	***0.58***		2.34	

TEST SETUP			**C-cfm**	**n**
1j2	2	1	0.77	0.64
3j4	2	1	0.77	0.51
Average of 2 single joints samples			0.77	0.58
1j2j3j4	4	3	1.66	0.67
Average per Joint Unit			0.55	-
SERIES AVERAGE-Per 1 Joint			**0.66**	**0.62**

Table A.11 Power Law Constants C and n for Branched Duct System with Beaded Slip Joints Spiro Sealed

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg ΔP*=P/P_{ref}	log Q-cfm Q=(m^3/h)/1.69	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.003	400	0.339	0.204	-0.69753	***0.31***	***0.63***	***0.74***	0.56	0.15	0.34
	2	1	0.004	1000	0.452	0.602	-0.57259	2.22	1.71	***0.31***		0.27	
	2	1	0.006	1200	0.678	0.681	-0.39650	1.29	***0.63***	2.22		0.40	
	2	1	0.008	1500	0.904	0.778	-0.27156	1.29	1.71	***0.74***		0.54	
3j4	2	1	0.003	400	0.339	0.204	-0.69753	***0.31***	***0.63***	***0.64***	0.57	0.15	0.32
	2	1	0.004	1000	0.452	0.602	-0.57259	2.22	1.38	***0.31***		0.27	
	2	1	0.006	1200	0.678	0.681	-0.39650	***0.69***	***0.63***	2.22		0.40	
	2	1	0.007	1500	0.791	0.778	-0.32956	***0.69***	1.38	***0.64***		0.47	
5j6	2	1	0.002	400	0.226	0.204	-0.87362	***0.44***	***0.83***	***0.83***	0.73	0.09	0.26
	2	1	0.003	1000	0.339	0.602	-0.69753	2.80	1.71	***0.44***		0.20	
	2	1	0.005	1200	0.565	0.681	-0.47568	***0.82***	***0.83***	***2.80***		0.33	
	2	1	0.006	1500	0.678	0.778	-0.39650	***0.82***	1.71	***0.83***		0.40	
7j8	2	1	0.001	400	0.113	0.204	-1.17465	***0.76***	1.26	1.22	0.76	0.05	0.20
	2	1	0.002	1000	0.226	0.602	-0.87362	3.80	2.26	***0.76***		0.13	
	2	1	0.004	1200	0.452	0.681	-0.57259	1.00	1.26	3.80		0.27	
	2	1	0.005	1500	0.565	0.778	-0.47568	1.00	2.26	1.22		0.33	
1j2j3j4...j8	8	7	0.013	400	1.413	0.204	-0.07774	***0.74***	***0.76***	***0.69***	0.66	0.61	1.57
	8	7	0.025	1000	2.791	0.602	0.21782	***0.84***	***0.58***	***0.74***		1.65	
	8	7	0.029	1200	3.250	0.681	0.28398	***0.37***	***0.76***	***0.84***		1.92	
	8	7	0.031	1500	3.533	0.778	0.32020	***0.37***	***0.58***	***0.69***		2.09	
Average of 4 single joints samples			0.28	0.65									
1j2j3j4	8	7	1.57	0.66									
Average per Joint Unit			0.22	-									
SERIES AVERAGE			**0.25**	**0.66**									

Table A.12 Power Law Constants C and n for Branched Duct System with Beaded Slip Joints Trelleborg Sealed

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg ΔP*=P/P_{ref}	log Q-cfm Q=(m^3/h)/1.69	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.003	400	0.339	0.204	-0.69753	0.56	0.63	0.58	0.56	0.15	0.33
	2	1	0.005	1000	0.565	0.602	-0.47568	1.00	0.65	0.56		0.33	
	2	1	0.006	1200	0.678	0.681	-0.39650	0.36	0.63	1.00		0.40	
	2	1	0.007	1500	0.735	0.778	-0.36174	0.36	0.65	0.58		0.43	
3j4	2	1	0.002	400	0.226	0.204	-0.87362	0.76	0.83	0.77	0.71	0.10	0.27
	2	1	0.004	1000	0.452	0.602	-0.57259	1.22	0.79	0.76		0.27	
	2	1	0.005	1200	0.565	0.681	-0.47568	0.43	0.83	1.22		0.33	
	2	1	0.006	1500	0.622	0.778	-0.43429	0.43	0.79	0.77		0.37	
5j6	2	1	0.002	400	0.226	0.204	-0.87362	0.76	0.83	0.77	0.71	0.10	0.27
	2	1	0.004	1000	0.452	0.602	-0.57259	1.22	0.79	0.76		0.27	
	2	1	0.005	1200	0.565	0.681	-0.47568	0.43	0.83	1.22		0.33	
	2	1	0.006	1500	0.622	0.778	-0.43429	0.43	0.79	0.77		0.37	
7j8	2	1	0.002	400	0.226	0.204	-0.87362	0.76	1.00	0.89	0.67	0.10	0.30
	2	1	0.004	1000	0.452	0.602	-0.57259	2.22	1.20	0.76		0.27	
	2	1	0.006	1200	0.678	0.681	-0.39650	0.36	1.00	2.22		0.40	
	2	1	0.007	1500	0.735	0.778	-0.36174	0.36	1.20	0.89		0.43	
1j2j3j4...j8	8	7	0.014	400	1.540	0.204	-0.04032	0.74	0.70	0.66	0.58	0.69	1.66
	8	7	0.027	1000	3.038	0.602	0.25469	0.49	0.47	0.74		1.80	
	8	7	0.029	1200	3.321	0.681	0.29332	0.45	0.70	0.49		1.96	
	8	7	0.033	1500	3.674	0.778	0.33723	0.45	0.47	0.66		2.17	

Average of 4 single joints samples			0.30	0.63
1j2j3j4	8	7	1.66	0.58
Average per Joint Unit			0.24	-
SERIES AVERAGE			**0.27**	**0.61**

Table A.13 Power Law Constants C and n for Branched Duct System with Beaded Slip Joints Unsealed

TEST SETUP			TEST DATA		CALCULATED DATA			LOG Q = LOG C + (n x LOG ΔP*) Y= B + (A x X)					
Duct Sections	No of Duct Sections	No of Joints	Mean Velocity-m/s	Test Pressure (P)-Pa	Actual Air Flow Rate (Q)-m3/h	log ΔP*-inwg ΔP*=P/P_{ref}	log Q-cfm Q=(m^3/h)/1.69	n-Values <1 ....Turbulent Flow				Air Leakage Coefficient-C-cfm	
1j2	2	1	0.006	400	0.622	0.204	-0.43429	***0.09***	***0.22***	***0.23***	0.38	0.31	0.42
	2	1	0.006	1000	0.678	0.602	-0.39650	***0.85***	***0.55***	***0.09***		0.40	
	2	1	0.007	1200	0.791	0.681	-0.32956	***0.31***	***0.22***	***0.85***		0.47	
	2	1	0.008	1500	0.848	0.778	-0.29959	***0.31***	***0.55***	***0.23***		0.50	
3j4	2	1	0.005	400	0.565	0.204	-0.47568	***0.20***	***0.17***	***0.36***	0.36	0.28	0.41
	2	1	0.006	1000	0.678	0.602	-0.39650	0.00	***0.71***	***0.20***		0.40	
	2	1	0.006	1200	0.678	0.681	-0.39650	1.29	***0.17***	0.00		0.40	
	2	1	0.008	1500	0.904	0.778	-0.27156	1.29	***0.71***	***0.36***		0.54	
5j6	2	1	0.005	400	0.565	0.204	-0.47568	***0.20***	***0.31***	***0.36***	0.50	0.26	0.42
	2	1	0.006	1000	0.678	0.602	-0.39650	***0.85***	***0.71***	***0.20***		0.40	
	2	1	0.007	1200	0.791	0.681	-0.32956	***0.60***	***0.31***	***0.85***		0.47	
	2	1	0.008	1500	0.904	0.778	-0.27156	***0.60***	***0.71***	***0.36***		0.54	
7j8	2	1	0.005	400	0.565	0.204	-0.47568	***0.20***	***0.31***	***0.25***	0.33	0.29	0.41
	2	1	0.006	1000	0.678	0.602	-0.39650	***0.85***	***0.38***	***0.20***		0.40	
	2	1	0.007	1200	0.791	0.681	-0.32956	***0.00***	***0.31***	***0.85***		0.47	
	2	1	0.007	1500	0.791	0.778	-0.32956	***0.00***	***0.38***	***0.25***		0.47	
1j2j3j4...j8	8	7	0.030	400	3.391	0.204	0.30247	***0.13***	***0.29***	***0.29***	0.32	1.73	2.42
	8	7	0.034	1000	3.815	0.602	0.35362	1.10	***0.64***	***0.13***		2.26	
	8	7	0.041	1200	4.663	0.681	0.44077	***0.26***	***0.29***	1.10		2.76	
	8	7	0.044	1500	4.946	0.778	0.46632	***0.26***	***0.64***	***0.29***		2.93	
Average of 4 single joints samples			0.41	0.37									
1j2j3j4	8	7	2.42	0.32									
Average per Joint Unit			0.35	-									
SERIES AVERAGE			**0.38**	**0.35**									

APPENDIX B

SOME FOTOGRAPHS FROM TESTING

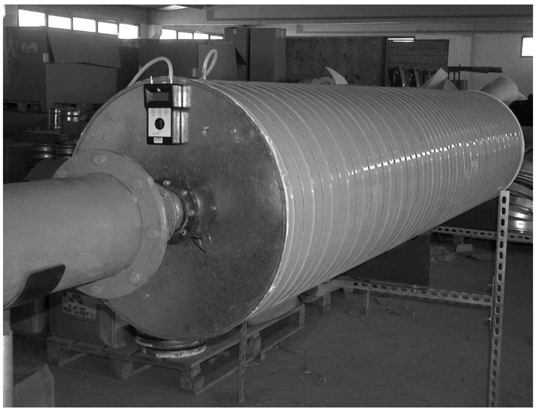


Figure B1.Test System for Circular Duct

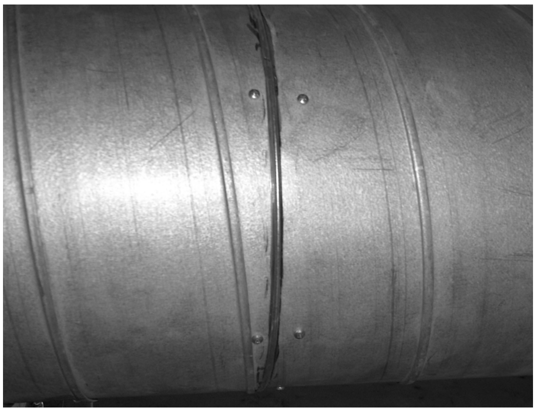


Figure B2.Beaded Slip Joint Type

Figure B3.Beaded Slip Coupler

Figure B4.Assembly of An Elbow

Figure B5.Corrugation in a Circular Duct

Figure B6.Assembly of Test Apparatus

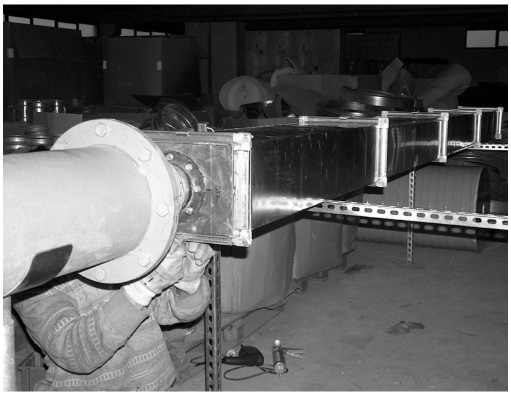


Figure B7.Test System for Rectangular Duct

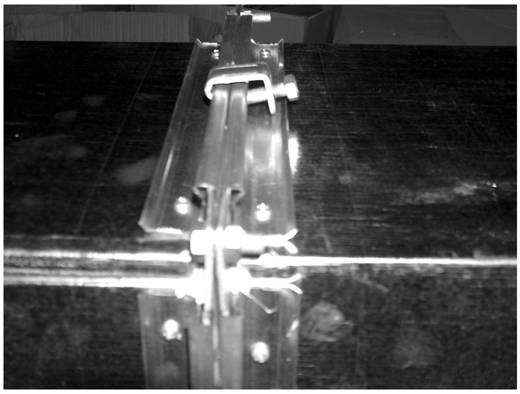


Figure B8.Flange Joint Type

Figure B9.Corner for Rectangular Duct

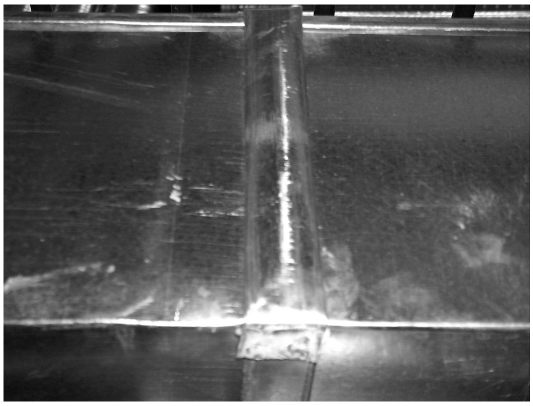
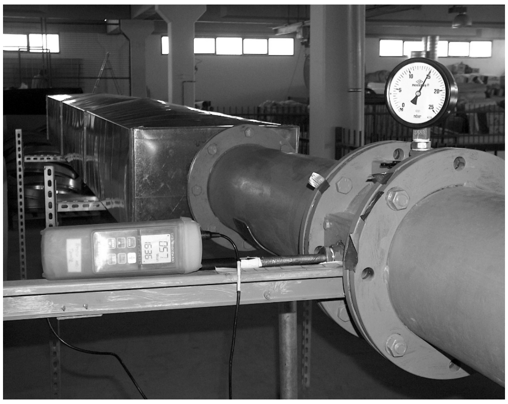


Figure B10.Drive Slip Joint Type

Figure B11.Test System for Rectangular

Figure B12. Drive Slip J. under Pressure



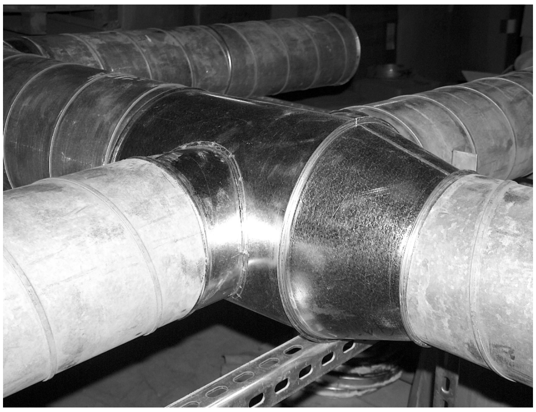


Figure B13.Assembly of Anemometer Figure B14. Beaded Slip Joint under Pressure

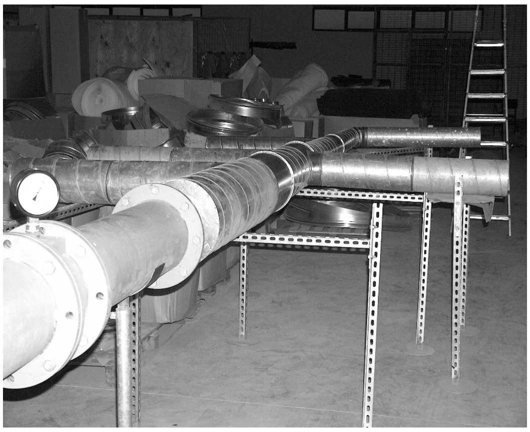


Figure B15.Reducing Te-Piece Figure B16. Dist.System under Pressure

Figure B17. Assembly of Distribution System

APPENDIX C

NATIONAL STANDARDS

This chapter gives an overview of standards related to the airtightness of air distribution system in Europe, England and Turkey.

EUROVENT 2/2 - 1996

AIR LEAKAGE RATE IN SHEET METAL AIR DISTRIBUTION SYSTEMS

EUROVENT / CECOMAF

2. LIMITATIONS OF VALIDITY

2.1 Experiments have indicated that, for a wide range of ductwork varying in sectional area, method of manufacture and sealing, and providing that the minimum static gauge pressure is not less than half the maximum static pressure, then $f.p^{0,65}$ is substantially constant within a range of normal conditions.

Therefore static gauge pressure testing of site installed ductwork can be accepted as a satisfactory test of acceptable leakage under operating conditions.

2.2 For normal ventilating and air-conditioning installations, three classes of air tightness, A, B, and C have been chosen for which the limits of leakage ($f.p^{0.65}$) are defined as :

Air tightness classes for installed duct testing :

Air tightness class	f_{max} $1.s^{-1}.m^{-2}$
A	$0.027.p^{0.65}$
B	$0.009.p^{0.65}$
C	$0.003.p^{0.65}$

Air tightness classes for laboratory duct testing :

Air tightness class	f_{max} $1.s^{-1}.m^{-2}$
A	$(0,027.p^{0.65}).0.5$
B	$(0.009.p^{0.65}).0.5$
C	$(0.003.p^{0.65}).0.5$

Maximum leakage rate for different installed duct test pressures :

Static gauge	Maximum leakage per class ($1.s^{-1}.m^{-2}$)		
	A	B	C
400	1.32	0.44	
1000		0.80	
1200			0.30
1500			0.35

Maximum leakage rate for different laboratory test duct pressures :

Static gauge	Maximum leakage per class ($1.s^{-1}.m^{-2}$)		
	A	B	C
400	0.66	0.22	
1000		0.40	
1200			0.15
1500			0.17

3. CHOICE OF AIR TIGHTNESS CLASS

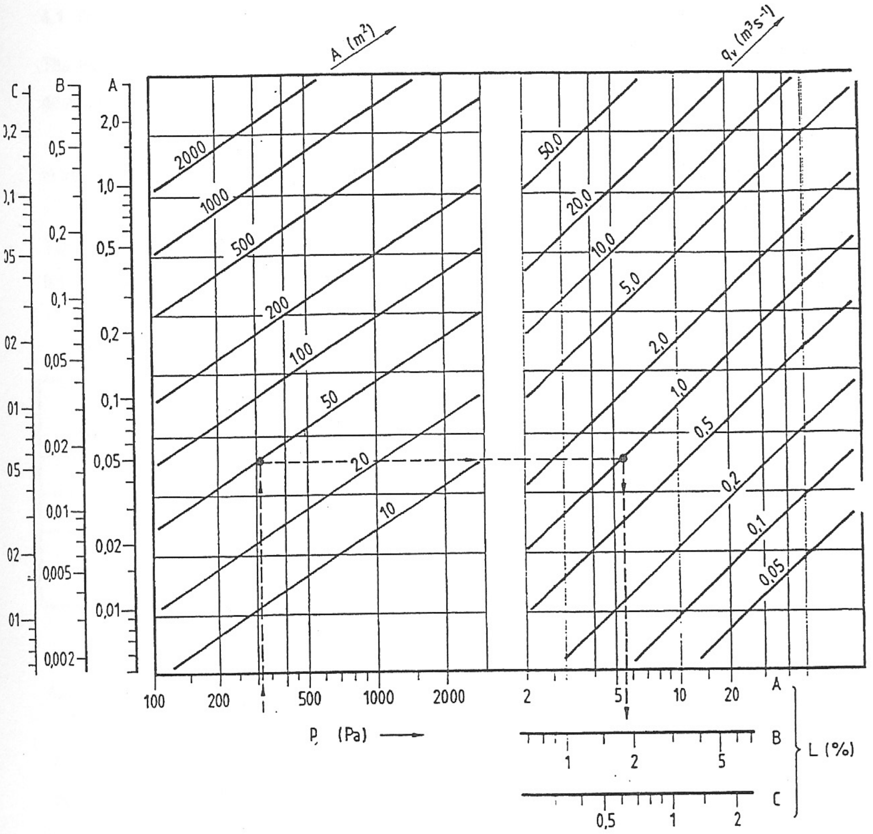
In order to assess permitted leakage it is useful to relate this to total air flow rate.

Fig. 1 can be used to assess this permitted leakage for systems in which all components ductwork are required to be of the same air tightness class.

From the parameters « mean pressure » (p_{sm}) and Surface Area of ducting (A) the per. leakage rate for classes A, B and C can be obtained.

From the parameter « Air flow rate » (q_v), the leakage for classes A, B and C ca ascertained as a percentage air loss.

Table 1 - Value of the maximum leakage for the three classes at three typical test pressures



Symbol	QUANTITY
q_{v1}/m^2	Leakage volume flow rate of ducting to be tested
A	Surface area of ducting to be tested
q_v	System air flow rate
p_{sm}	Arithmetical mean value of static gauge pressures
L	leakage in % of system air flow rate

4. TESTING

4.1 Test Pressure

The test pressure for Class A or B ductwork should not exceed 1000 Pa or the maximum design static gauge duct pressure, whichever is the smaller.

In the case of Class C ductwork the test pressure can be increased to 2000 Pa.

Table 1 shows the value of the maximum allowed leakage rates for the three classes at typical test pressures for installed ducting.

Table 1

Class	Max. Leakage factor	Test static gauge pressure (p_s)			
	$m^3m^{-2}s^{-1}$	2000 Pa	1000 Pa	400 Pa	200 Pa
A	f_A	-	$2,4 . 10^{-3}$	$1,32 . 10^{-3}$	$0,84 . 10^{-3}$
B	f_B	-	$0,8 . 10^{-3}$	$0,44 . 10^{-3}$	$0,28 . 10^{-3}$
C	f_C	$0,42 . 10^{-3}$	$0,28 . 10^{-3}$	$0,15 . 10^{-3}$	-

4.2 Test apparatus

The test apparatus shall consist of an appropriate fan, with pressure control and means of flow rate measurement, together with an airtight connection to the section of ductwork under test.

4.3 Test procedure

4.3.1 Before commencing the test, the sections to be tested shall be sealed off from the rest of the system.

For circular ducts shall at least 10 % of the total surface area of the system shall be tested, and for rectangular ducts at least 20 % shall be tested.

In either case the area to be tested shall normally be at least 10 m^2. A normal ratio between the total joint-/seamlength (L) and area (A) is L/A = 1,5 m^{-1}.

4.3.2 The section to be tested shall first be subjected to a pressure not less than its design operating pressure.

4.3.3 The static gauge pressure ps in the duct shall be maintained within 5 percent of the specified figure.

This pressure shall be kept constant for 5 minutes. No reading shall be recorded until this has been stabilised.

4.3.4 If the air leakage rate excess the permitted rate, the test shall be extended to include additional same percentage of the total surface area. If the air leakage still excess the permitted rate, the total surface area shall be tested.

4.4 Test report

For each section tested the values of q_{v1}, p_s and A shall be recorded together with the calculation of f . $p_{sm}{+}^{o,65}$.

The results shall then be compared with the specified leakage value.

A typical test report is attached as an annex.

HVAC AIR DUCT LEAKAGE TEST MANUAL

FIRST EDITION
1985

SHEET METAL AND AIR CONDITIONING CONTRACTORS NATIONAL ASSOCIATION, INC.

LEAKAGE TESTING

SECTION 1 INTRODUCTION

1.1 This document identifies certain leakage limits for ducts and outlines procedures for testing ducts for conformity with air leakage limits that are set forth in a designer's project specification. This document is not an endorsement of routine use of testing. Leakage testing is generally an unjustified major expense that is unnecessary when proper methods of assembly and sealing are used. Visual inspection for application of such proper methods will ordinarily suffice for verification of reasonably tight construction. Under any circumstances reasonable allowances for leakage must be adopted because no duct is absolutely airtight.

1.2 The sealing provisions contained in the SMACNA HVAC Duct Construction Standards—Metal and Flexible, 1985 edition, are reproduced here for convenient understanding of use of prescriptive measures. Consult the SMACNA Fibrous Glass Duct Construction Standards for fibrous glass duct assembly. Closures of joints and seams in fibrous glass ducts rely on taped adhesive systems to make connections, in contrast with metal ducts which use mechanical locks for connection and use sealants for supplemental leakage control.

1.3 Duct leakage reduces the air quantities at terminal points unless the total air quantity is adjusted to compensate. Leakage should be considered a transmission loss in duct systems. The farther air is conveyed the greater the loss will be. Key variables that affect the amount of leakage are:

a) Static pressure, not velocity pressure. (The higher the pressure the more leakage will occur.)
b) The amount of duct (the more duct the more opportunity for leakage there will be).
c) The openings in the duct surface (the major contributors are joints and seams although access doors, rod penetrations and fastener penetrations also contribute).
d) Workmanship (poor workmanship undermines the best construction standards).

It is practical to relate leakage to duct surface area. Although rates of loss per foot of seam, per diameter of hole or per dimension of crack can be evaluated, duct surface area is the simplest parameter by which to evaluate system leakage. Furthermore, research (in Europe and independently in the United States) has led to the conclusion that within acceptable tolerances, a duct surface leakage factor can be identified by the following relationship.

$F = C_L P^N$ where

F is a leak rate per unit of duct surface area (typically cfm/100 s.f.)

C_L is a constant

P is static pressure (typically in inches water gage)

N is an exponent (most typically it is 0.65 but in some cases it is 0.5 to 0.9)

The new SMACNA Leakage Classifications are based on this leakage factor relationship. Whether the designer uses the rates identified or prefers other constants, it is practical to evaluate leakage by this method.

SECTION 4 LEAKAGE CLASSIFICATION

4.1 Leakage classification identifies a permissible leakage rate in cfm per 100 square feet of duct surface according to the relationship $C_l = F \div (P)^{.65}$ as defined in Section 1.3.

F is the leakage rate in cfm/100 s.f. of duct surface (It varies with static pressure).

P is the static pressure. Values for $(P)^{.65}$ are given in Appendix E. When P = 1, C_l = F.

C_l is the leakage class and is a constant.

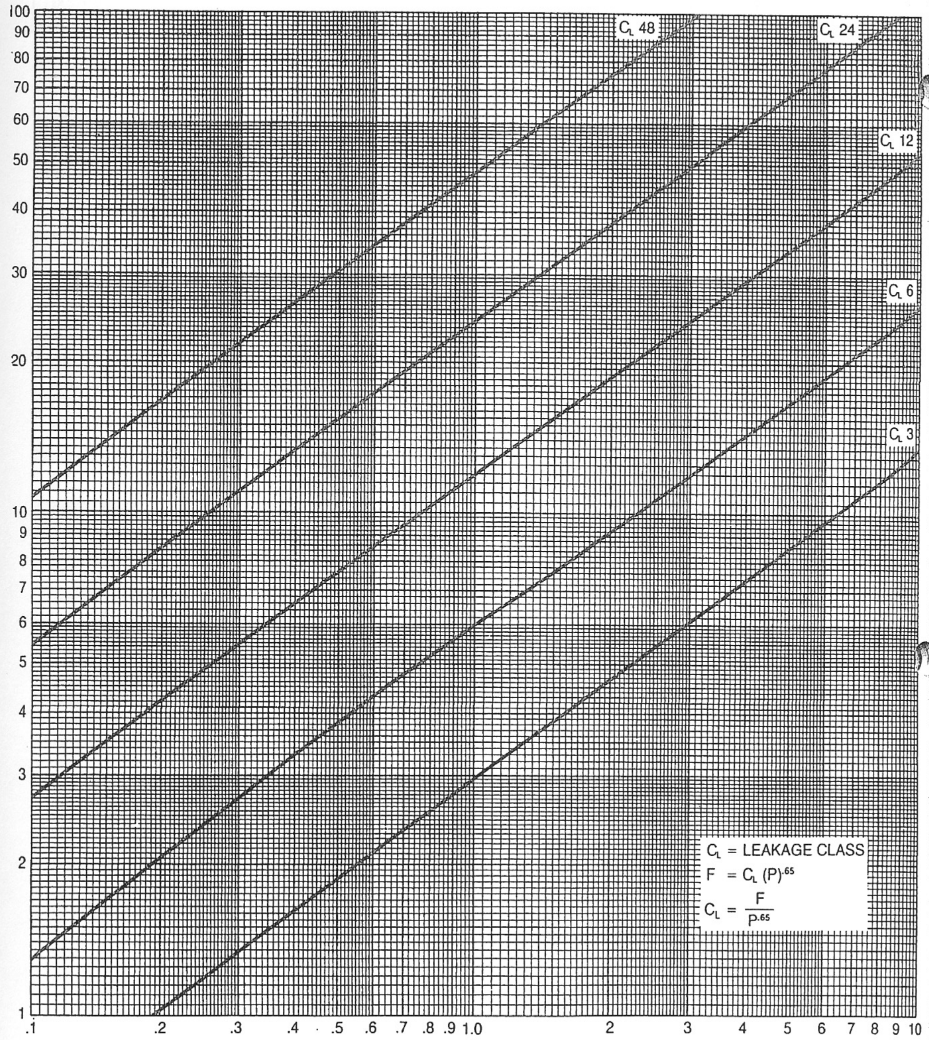
4.2 Leakage classifications 3, 6, 12, 24 and 48 are shown in Figure 1 for pressures up to 10" w.g. They are associated with duct type, seal classes, and construction pressure classes in Table 4-1. Table 4-1 is the basis of evaluating duct conforming to the SMACNA duct construction standards unless a specifier gives other limits.

4.3 If, at the specified test pressure, the leakage factor (F), by test, is lower than or equal to that associated with the specified leakage class, the duct is in compliance. Alternatively, if the leakage constant (C_L) determined from tests is lower than or equal to the specified leakage class, the duct is in compliance.

4.4 Assignment of leakage classes involves careful consideration of system size, duct location, sealing and construction class. Arbitrary assignment of an allowable % of leakage in disregard of these factors can indicate unobtainable results. A 1/2% allowance, for example, on a 3900 cfm system with 1300 s.f. of duct or on a 39,000 cfm system with 13,000 s.f. of duct would mean an unrealistic leakage factor of 1.5 cfm/100 s.f. in each case. Similarly, arbitrary assignment of 10" w.g. class construction for a system operating at 1" w.g. in order to get leak class 3 rectangular duct would not be cost effective. Assigning a leakage class 3 to a 1" w.g. rectangular duct system may address an achievable result but the associated difficulty and costs will be excessive. Table 4-1 represents the leakage expected using Seal Classes A, B, and C as indicated on duct construction of the types typically selected for each pressure class. Conceivably Seal Class B or A could be applied at construction pressure classes lower than indicated in Table 4-1. However, unless joint type, seam type, duct wall thickness and specific sealing method were already collectively prequalified by tests (or by an acceptable experience record at a higher pressure) leakage rate is less predictable. The benefits of setting allowable leakage rates lower than shown in Table 4-1 should be carefully weighed against the costs of achieving them.

4.5 A sample leakage classification analysis is given in Appendix B.

4.6 No leakage tests are required by the SMACNA duct construction standards or by this leakage test manual. When the designer has only required leakage tests to be conducted in accordance with the SMACNA HVAC Duct Leakage Test Manual for verification that the leakage classifications in Table 1 have been met (and has given no other criteria and scope), he is deemed to have not fulfilled the responsibilities outlined in Section 2.1 for providing a clear scope of work. When duct construction pressure classes are not identified in the contract drawings and the amount of leakage testing is not set forth in the contract documents, any implied obligation of the installer to fulfill the responsibilities under Section 2.2 in regard to leakage are deemed to be waived by defective specification.



PRESSURE IN INCHES OF WATER

SEE TABLE 4-1 FOR ASSOCIATED DUCT CONSTRUCTION CLASS

SEE APPENDIX E FOR TABULAR FORM OF FIGURE 4-1

DUCT LEAKAGE CLASSIFICATION

FIG. 4-1

TABLE 4-1 APPLICABLE LEAKAGE CLASSES			
DUCT CLASS	1/2", 1", 2" W.G.	3" W.G.	4", 6", 10" W.G.
SEAL CLASS	C	B	A
SEALING APPLICABLE	TRANSVERSE JOINTS ONLY	TRANSVERSE JOINTS AND SEAMS	JOINTS, SEAMS AND ALL WALL PENETRATIONS
LEAKAGE CLASS			
RECTANGULAR METAL	24	12	6
ROUND METAL	12	6	3

NOTES:

1. Leakage classes in Table 4-1 apply when the designer does not designate other limits and has specified Seal Class C for 1/2" and 1" w.g. See text on sealing in the HVAC-DCS manual.
2. Unsealed rectangular metal duct may follow Leakage Class 48.
3. Fibrous glass duct may follow Leakage Class 6 (at 2" w.g. or less).
4. Unsealed flexible duct leakage average is estimated to be Class 30. Sealed nonmetal flexible duct is an average of Class 12.
5. See SMACNA HVAC Duct Systems Design manual Table 5-1 for longitudinal seam leakage rates.
6. Although Seal Class A or B might be assigned for lower pressures, the leakage class may not conform to those associated with the higher pressure. Other construction details influence results.
7. Leakage Class (C_L) is defined as being the leakage rate (CFM/100 S.F.) divided by $P^{.65}$ where P is the static pressure (IN. W.G.). When P is numerically equal to 1" the leakage rate is C_L. See Figure 4-1.
8. The duct pressure classification is not the fan static pressure nor the external static pressure (on an HVAC unit) unless the system designer has made such an assignment in his contract documents. Unless construction class is otherwise specified it means a static pressure classification in the SMACNA HVAC-DCS. Those classifications pertain to maximum operating pressure in the duct as follows:

0.5" w.g. maximum	3.1" to 4" w.g. maximum
0.6" to 2" w.g. maximum	4.1" to 6" w.g. maximum
1.1" to 2" w.g. maximum	6.1" to 10" w.g. maximum
2.1" to 3" w.g. maximum	

SECTION 5 TEST APPARATUS

5.1 Test apparatus shall consist of an airflow measuring device, flow producing unit, pressure indicating devices and accessories necessary to connect the metering system to the test specimen.

5.2 The contractor conducting tests shall arrange for or provide all temporary services, all test apparatus, all temporary seals and all qualified personnel necessary to conduct the specified testing.

5.3 Test apparatus shall be accurate within plus or minus 7.5% at the indicated flow rate and test pressure and shall have calibration data or a certificate signifying manufacture of the meter in conformance with the ASME Requirements for Fluid Meters. ASME qualified orifice meters do not require calibration.

5.4 Unless otherwise specified, test apparatus shall be used as outlined in this section, as described in Section 3 and as recommended for good practice.

5.5 Typical construction and use of orifice meters is indicated in Figures 5-1 and 5-2. Typical orifice selections are shown in Figure 5-3.

5.6 The use of flow nozzles, venturi meters, laminar flow meters, rotameters, Pitot tube meters or other meters having equivalent accuracy and suitability is not prohibited by the references herein to orifice meters.

5.7 The recommended minimum thicknesses for orifice plates in tubes of various diameters are 1/16″ to 6″ diameter, 3/32″ to 12″ diameter and 1/8″ for larger diameters. Steel or stainless steel plate material is preferable. Plates shall be flat and have holes with square edges (90°) that are free of burrs. Orifice openings shall be centered in the meter tube. Plates shall be perpendicular to the flow path and shall be free of leaks at points of attachment.

5.8 Taps for static pressure indication across orifices shall be made with 1/16″ to 1/8″ diameter holes drilled neatly in the meter tube wall. The interior of the tube shall be smooth and free of projections at the drilled holes.

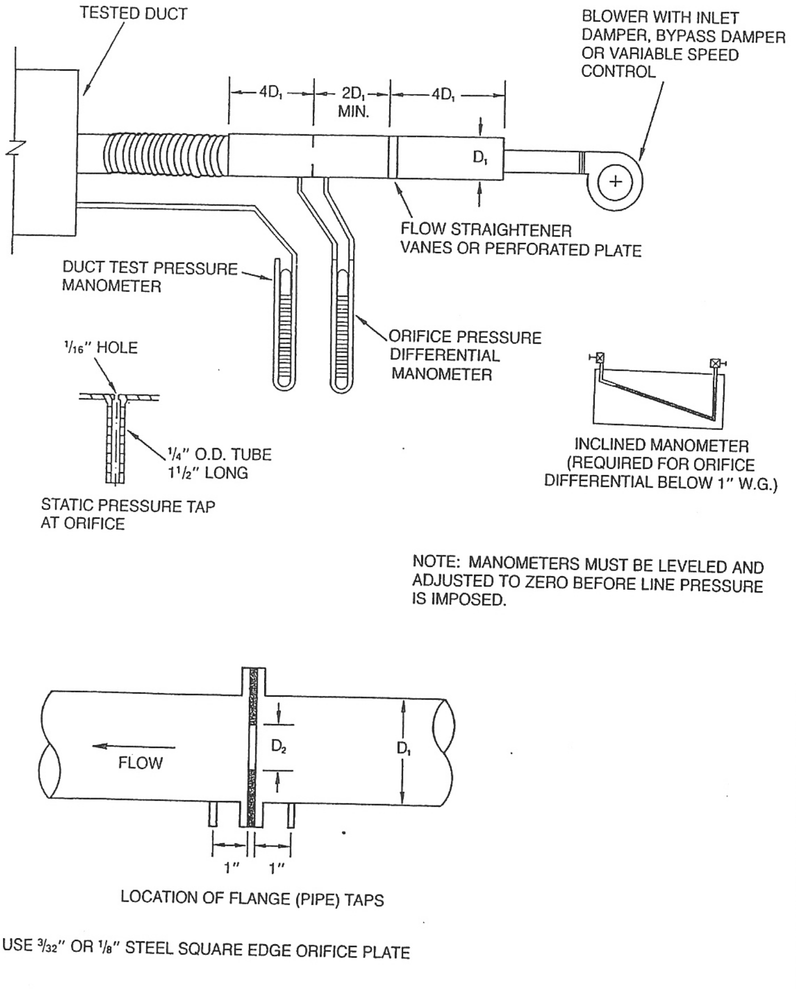
5.9 Pressure differential sensing instruments shall be readable to 0.05″ scale division for flow rates below 10 cfm or below 0.5″ w.g. differential. For higher flow scale divisions of 0.1″ are appropriate. U-tube manometers should not be used for readings less than 1″ of water.

5.10 Liquid for manometers shall have a specific gravity of 1 (as water) unless the scale is calibrated to read in inches of water contingent on use of a liquid of another specific gravity, in which case the associated gage fluid must be used.

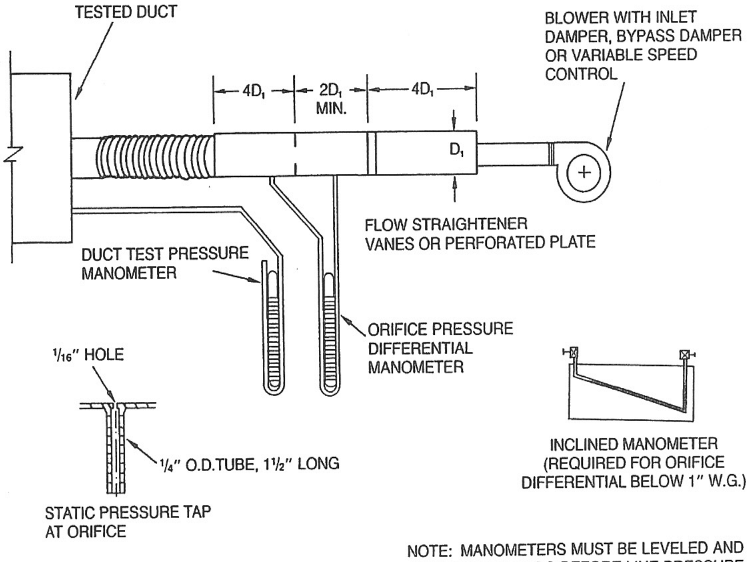
5.11 The duct test pressure shall be sensed only from an opening in the duct.

5.12 The illustration of the flowmeter on test blower discharge does not preclude use of it on the suction side.

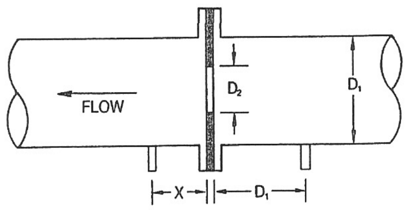
5.13 Instruments must be adjusted to zero reading before pressure is applied.



LEAKAGE TEST METER APPARATUS—FLANGE TAPS **FIG. 5-1**



NOTE: MANOMETERS MUST BE LEVELED AND ADJUSTED TO ZERO BEFORE LINE PRESSURE IS IMPOSED.



LOCATION OF VENA CONTRACTA TAPS

USE 3/32" OR 1/8" STEEL SQUARE EDGE ORIFICE PLATE

D_2/D_1	X
0.2	0.74 D_1
0.3	0.71 D_1
0.4	0.66 D_1
0.5	0.60 D_1
0.6	0.53 D_1
0.7	0.45 D_1
0.8	0.36 D_1

LEAKAGE TEST METER APPARATUS—VENA CONTRACTA TAPS **FIG. 5-2**

5.14 Airflow across a sharp edge orifice with standard air density of .075 #/ft³ is calculated from

$$Q = 21.8\ K\ (D_2)^2\ \sqrt{\Delta P}$$

(Equation 1)

Where
Q = air volume, cfm
K = coefficient of airflow from Table 5-1 or Appendix J
D = orifice diameter, inches (D_2)
ΔP = pressure drop across orifice, inches w.g.

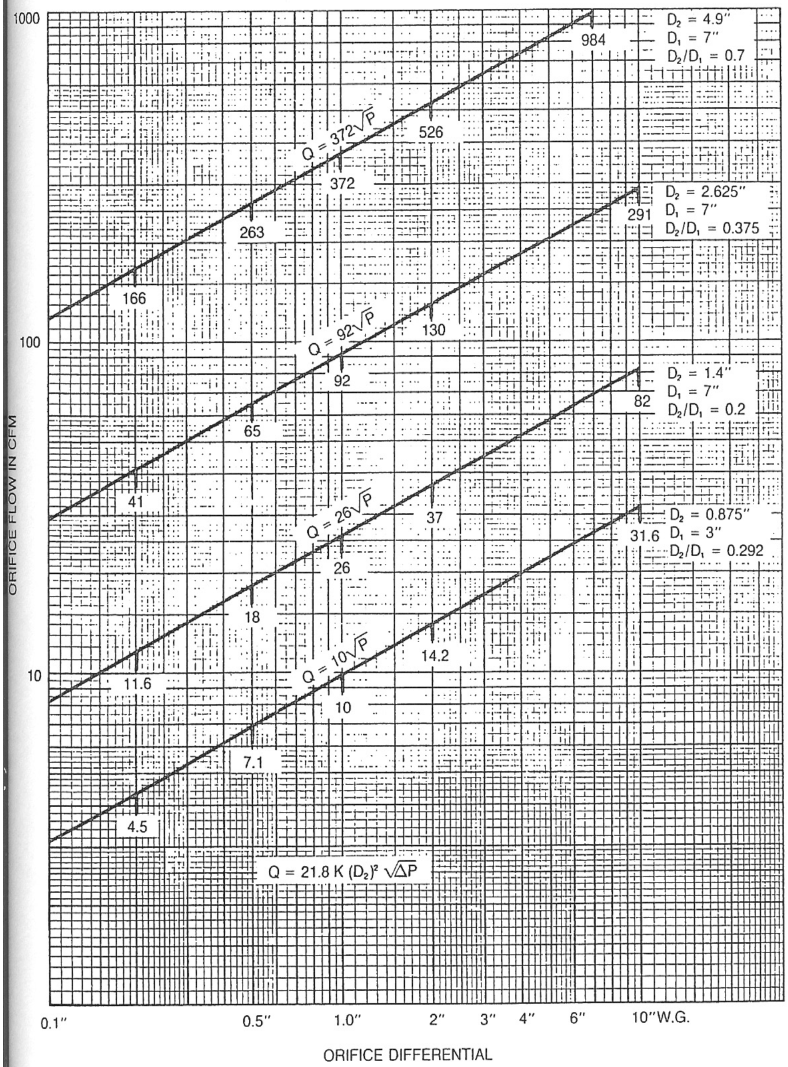
TABLE 5-1
ORIFICE COEFFICIENTS

D_2/D_1	.70	.60	.50	.40	.30
A_2/A_1	.490	.36	.250	.160	.090
K	.699	.650	.623	.608	.600
Kp	.52	.63	.73	.82	.88

The ratio of orifice diameter D_2 to meter tube interior diameter D_1 is known as the Beta (β), or diameter ratio. It is normally selected in the range of 0.7 to 0.3. The orifice-to-tube area ratio (A_2/A_1) is an indication of the contraction of flow. Kp in Table 5-1 is the overall pressure loss that occurs from contracting and expanding the flow. Thus, the orifice causes a $Kp \times \Delta P$ loss that affects blower capacity.

5.15 Select a flowmeter suitable for the leakage in the duct to be tested:

a) Using the target leakage rate (cfm/100 s.f.) for the desired amount of tested duct find the cfm required. At this cfm the blower will have to produce a pressure approximately equal to the sum of the duct test pressure and the orifice differential pressure. Add 0.5″ w.g. if D_2/D_1 is less than 0.5. This assumes that there are no extraordinary pressure losses in the test meter and duct connecting it to the test specimen.
b) Select the meter from Figure 5-3 or use Table 5-1 and Equation 1 to size a meter that will have a flow curve of the desired range and still be within the capacity of the blower. Characteristics of typical orifices are shown in Table 5-2.



TYPICAL ORIFICE FLOW CURVES **FIG. 5-3**

5.16 Precautions to be followed for test apparatus:

a) Start the blower with blocked suction or discharge to avoid overpressurizing ductwork.
b) Use clean manometers.
c) Heat manometers to avoid freezing fluid in cold weather.
d) If manometer fluid is blown out; refill with the appropriate fluid; for convenience add a drop of water soluble dye to water-filled manometers.
e) Level position sensitive instruments and set them to zero scale reading.
f) Read liquid levels by viewing them horizontally.
g) Record instruments used for testing.

DW/143

A practical guide to – DUCTWORK LEAKAGE TESTING

Based on the requirements of DW/142 specification for sheet metal ductwork 1983

HEATING AND VENTILATING
CONTRACTORS' ASSOCIATION
Esca House, 34 Palace Court,
London W2 4JG
Telephone: 071-229 2488
Telex: 27929

Obtainable from: HVCA Publications,
Old Mansion House, Eamont Bridge, Penrith,
Cumbria, CA10 2BX
Telephone: Penrith (0768) 64771 Telex: 64326
Price: £5 (including inland postage)
Overseas: Surface mail £6.50 Air Mail £7.00

Part Two

This section is predominantly extracted from DW/142 – Specification for Sheet Metal Ductwork, and for ease of reference the numbering as in DW/142 has been retained. The leakage limits for EUROVENT classifications A, B and C, as set out in their document 2/2 (Air Leakage in Ductwork) have been adopted for the low pressure, medium pressure and high pressure Class C classifications. EUROVENT document 2/2 has no standard for a leakage class equivalent to our Class D and therefore the leakage limits for high pressure ductwork used in DW/141 (the predecessor to DW/142) have been retained.

6 AIR LEAKAGE STANDARDS

6.1 Limits for each pressure class

Permitted air leakage is related to four standards of airtightness, as set out in Table 2.

6.2 Compatibility with EUROVENT

The leakage factors used in Table 2 for Classes A, B and C are the same as those used for the classes similarly designated in the Eurovent Document 2/2 (Air Leakage in Ductwork).

6.3 Leakage at various pressures; and other relationships

Applying the limits specified in Table 2, Appendix A (Table 31) sets out the permitted leakage at each of a series of pressures up to the maximum for each class. Included in that appendix is a graphical presentation of the pressure/leakage relationship; and also charts from which may be determined leakage as a percentage of airflow for classes A, B or C.

Appendix A also gives details of the basis for the leakage limits specfied in Table 2.

6.4 Testing for air leakage

All ductwork operating at pressures classified in this specification as 'high pressure' shall be tested to establish conformity with the relevant leakage limits set out in Table 2.

Testing for leakage of ductwork within the low and medium ranges of pressure in this specification will not form part of the ductwork contract unless this requirement is set out in the job specification – see also Note (2) on page 1 of DW 142.

Table 2 Air Leakage Limits

Air leakage	Leakage limit
1	*2*
	litres per second per square metre of duct surface area
Low-pressure– Class A	$0.027 \times p^{0.65}$
Medium-pressure– Class B	$0.009 \times p^{0.65}$
High-pressure– Class C	$0.003 \times p^{0.65}$
High-pressure– Class D	$0.001 \times p^{0.65}$

where p is the differential pressure in pascals

APPENDIX A – AIR LEAKAGE FROM DUCTWORK

A.1 GENERAL CONSIDERATIONS

A.1.1 Leakage points in ductwork

Air leakage in installed ductwork occurs almost entirely at the longitudinal seams and the cross joints, particularly at the corners, and at the intersection of the seams and cross joints.

A.1.2 Leakage related to duct area

In practice, leakage can be taken as proportional to the surface area of the ductwork, whether rectangular or circular, even though there may be considerable variation in different sections of a complete system because of the changing sizes of the ducts and the number and variety of the fittings. The surface area is easily calculable as part of the design procedure.

A.1.3 Pressure/leakage relationship

For a given pressure, the leakage through an orifice of a given area will vary according to its shape. With installed ductwork, the leakage orifices are of differing shapes, so a precise value cannot be given to the pressure/leakage relationship. However, Swedish tests on a variety of constructions have shown that for ductwork operating within the range covered in this specification, leakage can be taken as proportional to pressure to the power of 0.65. (This value has been adopted by EUROVENT in preparing their Document 2/2 – Air Leakage in Ductwork – see Appendix L – and has also been adopted in this specification (see Table 2) and has been applied in Table 31.

A.2 LEAKAGE LIMITS – RELATIONSHIPS

A.2.1 Limits for each pressure class

Applying the values given in Table 2 (page 13), the permitted leakage at each of a series of pressures up to the maximum for each class is set out in Table 31.

A.2.2 Graphical presentation

The pressure/leakage relationships given in Table 31 are expressed graphically in Fig. 169.

A.2.3 Leakage as a percentage of airflow

As air leakage is related to surface area of the ductwork, it cannot in advance of the detailed calculations be expressed as a percentage of total airflow, nor will a percentage loss be acceptable as a standard of performance. However, application of the leakage limits to a variety of ductwork systems indicates that under oparating conditions air losses will usually be within 6 per cent of total airflow for the low-pressure class and 3 per cent for the medium-pressure class. For the high-pressure class, air loss is likely to be between 2 and 0.5 per cent, according to which leakage limit is applied.

A.2.4 Special cases

The percentages mentioned in A.2.3 apply to normal ratios of duct area to airflow; but where the ratio is high (e.g. long runs of small ducts), it may be necessary for the designer to specify a higher standard of airtightness in order to keep the actual leakage within an acceptable limit.

A.2.5 Designer's required calculations

Designers will be concerned with the total loss of air through leakage which must be allowed for the ductwork, and will need to:

(a) calculate the pressure class;

(b) calculate the surface area and estimate the mean system pressure difference for the ductwork system (or part of system);

Definition of mean pressure

$$Pm = \frac{P1 + P2}{2}, \text{ where:-}$$

Pm = mean or average pressure.

P1 = operating pressure at the beginning of the ductwork system or part of system.

P2 = operating pressure at the end of the ductwork system or part of system.

IT IS RECOMMENDED THAT MAXIMUM TEST PRESSURES AND LEAKAGE RATES SHOWN IN TABLE 32, PAGE 17, BE ADOPTED.

(c) calculate the total leakage using the appropriate rate from Table 31.

Alternatively, the designer may:

(d) decide on the maximum total leakage that he can accept;

(e) calculate the surface area and estimate the mean system pressure difference for the ductwork system (or part of system) and from these determine the required pressure class.

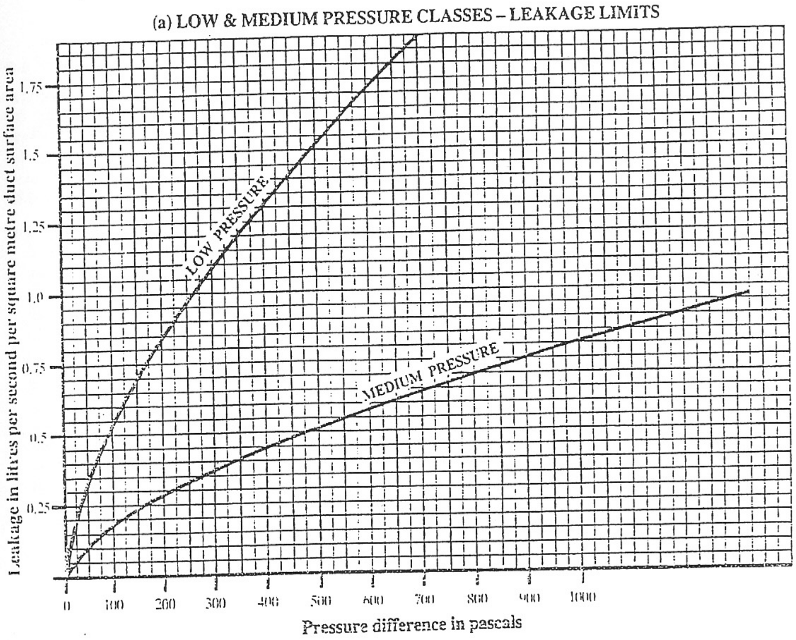
A.2.6 Leakage of complete system

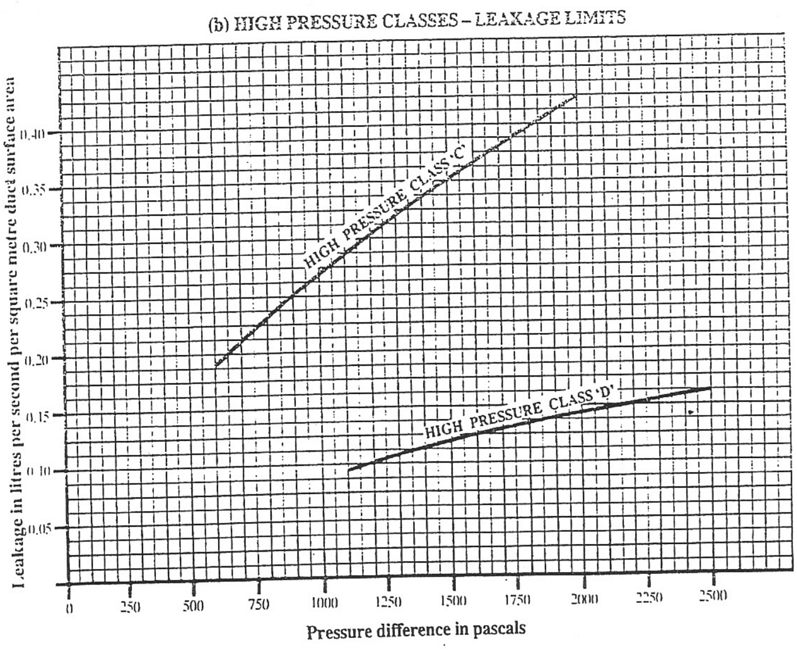
DW/142 deals only with the ductwork. The leakage characteristics of plant items and accessories are not within the control of the ductwork contractor, and therefore any leakage limits and leakage testing called for under DW/142 shall be understood to apply only to the ductwork itself.

Table 31 Air leakage rates

Static pressure differential	Maximum leakage of ductwork			
	Low-pressure Class A	Med-pressure Class B	High-pressure Class C	High-pressure Class D
1	2	3	4	5
Pa	Litres per second per square metre of surface area			
100	0.54	0.18		
200	0.84	0.28		
300	1.10	0.37		
400	1.32	0.44		
500	1.53	0.51		
600		0.58	0.19	
700		0.64	0.21	
800		0.69	0.23	
900		0.75	0.25	
1000		0.80	0.27	
1100			0.29	0.10
1200			0.30	0.10
1300			0.32	0.11
1400			0.33	0.11
1500			0.35	0.12
1600			0.36	0.12
1700			0.38	0.13
1800			0.39	0.13
1900			0.40	0.14
2000			0.42	0.14
2100				0.14
2200				0.15
2300				0.15
2400				0.16
2500				0.16

Fig. 169 Permitted leakage at various pressures





APPENDIX B – AIR LEAKAGE TESTING PROCEDURE

B.1 GENERAL

Section 6 (page 13) of this specification deals with the performance requirements of ductwork in respect of air leakage, and Table 31 (Appendix A) tabulates the limits of leakage applicable to each class of ductwork. Appendix B is solely concerned with recommendations for the testing procedure.

B.2 Extent of ductwork to be tested

B.2.1 The procedure set out in this section is limited to the ductwork. Terminal connections, and items such as air handling devices, terminal boxes, sound attenuators, heat exchangers, builder's work construction, are excluded from the tests.

B.2.2 The proportion of the ductwork to be tested and the method of selection (where not included in the job specification) should be determined in collaboration between the designer and the ductwork contractor. Where the method is by random selection, the use of polythene sheet or similar insertion blanks between duct cross joints and duct-mounted components will assist in avoiding delays in installation when tests are being carried out.

B.2.3 To enable the blank to be cut out after the testing is completed, access may be required adjacent to each blank. This procedure used on either side of a duct-mounted component will enable the component to be included in a subsequent additional test if specified.

B.2.4 Alternatively, rigid removable blanking plates can be used, although this involves remaking joints.

B.3 Testing to be completed before insulation, etc.

Testing shall be satisfactorily completed before insulation or enclosure of the ductwork and before terminal units (if any) are fitted.

B.4 Retesting procedure where necessary

B.4.1 The air leakage rate for any section shall not be in excess of the permitted rate for that section. If a first test produces leakage in excess of the permitted maximum, the section shall be resealed and retested until a leakage not greater than the permitted maximum for that section is achieved.

B.4.2 If at the time of witnessing the test it is apparent that excessive additional sealing of seams or joints has been done in order to meet the required leakage level, the section of ductwork under test shall not be counted as part of the tested ductwork, except where the whole of the ductwork is required to be tested.

B.5 Minimum area to be tested

The section of ductwork to be tested shall have an area large enough to enable the test apparatus to register a measurable leakage.

B.6 Test pressures and leakage rates

The maximum permissible leakage rates for the full range of pressures are given in Table 31. The recommended test pressures for the various classes of ductwork are set out in Table 32, and unless otherwise specified, the choice of test pressure shall be at the discretion of the test operator.

Table 32 Recommended maximum test pressures (with leakage rates)

Static pressure differential	Maximum leakage of ductwork			
	Low-pressure Class A	Medium-pressure Class B	High-pressure	
			Class C	Class D
1	*2*	*3*	*4*	*5*
Pa	Litres per second per square metre of surface area			
200	0.84			
400	1.32	0.44		
800		0.69		
1200			0.30	
1500			0.35	0.12
2000				0.14

B.7 Test apparatus

B.7.1 The accuracy of the test apparatus shall be within:

± 10 per cent of the indicated flow rate, or 0.4 litres per second, whichever is the greater; and

± 5 per cent at the indicated static pressure in the duct under test.

B.7.2 The test apparatus shall be inspected by the user before use on site, and shall have a calibration certificate, chart or graph dated not earlier than one year before the test for which it is used.

B.7.3 A diagram of a suitable test apparatus is given in Fig. 171.

B.8 Procedure

B.8.1 The section of ductwork to be tested for air leakage shall be sealed. Main ducts should be provided with flanged joints to enable blanking plates to be fitted, while small open ends may be sealed with polythene or inflatable bags, which should be left in position until final connections are made.

B.8.2 On low-pressure systems, final grille spigots made as a second fix operation shall be excluded from the test. The joint shall, where practicable, be checked by external visual examination.

B.8.3 Sufficient time shall be allowed between erection and leakage testing for sealants to cure.

B.8.4 Special care must be exercised in making all joints which fall outside the scope of the testing procedure, i.e., joints between tested sections of ductwork and between ductwork and other units.

B.8.5 Due notice of tests shall be given, so that arrangements for witnessing the tests, if required, can be made.

B.9 Testing sequence

The recommended sequence of testing is as follows.

B.9.1 Complete Part 1 of the Test Sheet.

B.9.2 Connect test apparatus to section of ductwork to be tested.

B.9.3 Adjust test apparatus until the static pressure differential is obtained.

B.9.4 Check that the measured leakage is within the permitted rate. (No addition shall be made to the permissible leakage rate for access doors, access panels or dampers where these are included in the ductwork.)

B.9.5 Maintain the test for fifteen minutes and check that the leakage rate has not increased.

B.9.6 Reduce pressure in section to zero by switching off the fan; then immediately re-apply test pressure to establish that the air leakage rate is not greater than the previous reading.

B.9.7 Record details on Part 2 of the Test Sheet and complete, including witnessing.

B.10 Air leakage test sheet

A specimen of a suitable Test Sheet is given on page 9.

Fig. 171 Diagram of typical apparatus for air leakage tests