PROGRESS AND TRENDS IN AIR INFILTRATION
AND VENTILATION RESEARCH

10th AIVC Conference, Dipoli, Finland
25-28 September, 1989

Poster 26

# DEMAND CONTROLLED AIR DUCTWORK

Juhani Laine

Technical Research Centre of Finland
Laboratory of Heating and Ventilating
Lampomiehenkuja 3
SF-02150 Espoo
Finland

## SYNOPSIS

A demand controlled air ductwork should be so dimensioned that the flow controllers have good flow and acoustical operation conditions. From the air flows in a room and its highest permissible sound level, the highest differential pressures allowable to the air flow controllers (duct air flow controllers and terminal devices) are selected. The required minimum differential pressure is 50-100 Pa or a higher differential pressure determined according to the outdoor temperature (-20°C), the height of the building and the air conditioning system required to control the thermal disturbing forces. From these differential pressures and the preadjustability of the air flows are determined the average pressure level of the ductwork and the highest permissible pressure losses of the air ducts, which at most may be about half the average pressure level. Also determined on the basis of the pressure level of the ductwork are the air tightness requirements in order to have control over the leakage noise. Suitable duct sizes have been ready-calculated. The pressure losses of the ducts are simply estimated from the pressure losses from local losses (bends and branches). Friction losses in the ducts are disregarded.

The dimensioning of the ducts should be adapted to the standards of the equipment technology (flow, acoustics, air tightness) that is available. The recommended total pressure loss (ducts and air flow controllers) of a demand controlled ductwork should be a maximum of around 200-300 Pa excluding the pressure loss of the central unit.

## 1. INTRODUCTION

The most important requirements in future techniques of controlling the indoor climates of buildings where human beings are concerned will be a steady, locally (by the room) controllable ideal temperature and quiet ventilation free of draughts, which will be controllable according to need.

In the air conditioning system of the future, air flows and thermal power will be controllable, in time and in place, in line with people's needs. To facilitate this, calculations and working experiments have been made from flow and acoustical simulations on air duct systems, and performances required of the equipment have been defined. This has been done in order to produce new principles of dimensioning air ducts, and simple methods of doing so.

## 2. PROBLEMS WITH PRESENT PRACTICE

### 2.1 Methods of dimensioning air ducts

Air ducts are usually dimensioned on the basis of pressure loss calculation for the air flow routes, or on the basis of old "empirical" duct velocities. Such traditional methods of dimensioning result in excessive velocities and pressure losses in air ducts, or in air ducts that are difficult to adjust and balance and that are acoustically uncontrolled, or in architectonically ugly air ducts often varying in diameter and subject to leakage. The dimensioning of the ducts should be adapted to the standards of the equipment technology that is available.

### 2.2 Adjusting, balancing and noise control

The higher the pressure loss of the ducts, the higher will be the differential pressures under which the air flow controllers (duct air flow controllers and terminal devices) have to function to balance the air flows, i.e. the pressures. The higher the differential pressures under which the air flow controllers have to function, the more difficult (or even impossible) and expensive will be the control of flows, and of noise levels in particular.

The problems and acoustical nuisance in adjusting and balancing present air ducts are chiefly due to the high pressure losses caused by excessive duct velocities. Consequences include the great throttling requirements on the dampers in branch ducts that cannot always be met even with dampers /5/, which produces ducts that are uncontrollable in terms of flow and acoustics. Air ducts intended for variable air flows cannot function as the air flow controllers, owing to high pressure losses at the beginning and/or end of the ductwork, may find it beyond their range of operation. This implies an obvious design fault, as the dimensioning of such ducts has not taken the technical level of the equipment into account. The high differential pressures cause the pressure in the ducts to become unreasonably high. The result will be noise arising from increased leakage and also great aesthetic nuisance at the places where the leaks occur, greater cleaning needs and an increase in the fan energy requirements. Because of the leakages, the pressure variations in the building may become uncontrollable, which is likely to cause disturbances in the form of draughts and condensation, and the spreading of bad odours and impurities.

The air flows, the pressures and the sound levels in the air duct system cannot be controlled unless the system is sufficiently airtight.

## 3. NEW PRINCIPLES OF DESIGNING AND DIMENSIONING

The ventilating, heating and cooling demands of buildings and the various premises they contain, and the quality of the air are the starting points for dimensioning the air flows and thereby the air ductwork. In actual practice the functions of the various premises in a building are often subject to alteration, perhaps even at the time when it is being designed and built. Once the building has been put into use, the purposes, loads and required quality levels of its various spaces may be subject to almost constant change.

The traditional determination of economical duct sizes and pressure losses has usually been based only on a comparison of capital costs for the ductwork and operating costs of the fans. But overall economy should be based on a far more extensive examination of the entire building, and in particular on the use to which it is being put.

The examination should cover the effects of the dimensioning of the ducts on the quality of the indoor climate produced by the air conditioning system and thus on human satisfaction; its effects on working efficiency, on the performance figures for energy and especially control technology, on ease of flow and acoustic adjusting, and on alterations to ducts and structures prompted by changes in use, and also on the costs of readjusting.

The method of dimensioning and designing the ductwork should be one in which errors in design or implementation do not essentially impair the flow or the acoustics of the system. The flow balance in the duct system should not be sensitive to changes in the flow of individual components. Good operating conditions should be created for flow controllers through the dimensioning of the ductwork.

## 4. TARGET FEATURES OF AIR DUCTWORK

Table 1 shows the target features for an air ductwork, controlled according to demands, which should be the basis of the dimensioning.

A dimensioning of the ducts that will implement these target features would even nowadays provide the opportunity for an economical implementation of air conditioning with variable air flows, which means one that can be controlled in terms of time and place. This is actually what the new Finnish regulations and guidelines /7/ aim at.

Table 1. Target features of demand controlled air ductwork.

| |
|---|
| * Significant performance in energy and control technology |
| * Functioning with variable air flows, i.e. allowing load variations |
| * Stable air flows |
| * Acoustically controlled |
| * Airtight |
| * Simple to design |
| * Self-adjusting or easy to preadjust |
| * Easy to use (operating status easily to check) |
| * Architectonically attractive |

## 5. CONTROL OF DUCT PRESSURES AND NOISE LEVELS

The air flows in the duct system balance at a level at which the total pressure loss of each air route from the fan to the room is equal. For the air flows to remain up to design in all flow conditions, ductwork should be designed to remain as symmetrical as possible in terms of pressure loss under variable air flows.

The air flow controllers should have sufficient authority for adjustment, meaning the differential pressure relative to the total pressure loss of the ductwork.

The air flows of the system cannot be controlled unless the pressures in the system are controlled. In the designing of the system there should be a shift from an examination of air flows alone, mainly to the controlling of air flows and of noise levels through duct pressures. By controlling air flows through duct pressures, also noise levels can be easily controlled with existing equipment.

## 6. DIMENSIONING OF AIR DUCTWORK

### 6.1 Principle of overall dimensioning

Pressure loss and the noise generation of various duct sizes and duct components have been examined by means of flow and acoustical calculation models /3/ of the duct system. If the transmission of sound from the duct into the room through the terminal devices and especially through the duct wall is also taken into account, the highest permissible duct velocities will be found, as will the greatest permissible sound power levels of the duct on the basis of the highest permissible noise level for the room. If account is taken, moreover, of the pressure losses necessary to accomplish adequate stability and control of air flows and to control the noise by leakage of the ductwork, it will be possible generally to select recommended duct sizes.

## 6.2 Noise attenuation requirement of air ductwork

The highest permissible sound power level of the fan and the air flow controllers in the ductwork must be held down to the highest permissible sound level for the room according to the recommended values in Table 2.

Table 2. Maximum recommended sound power level in duct, dB.

| Flow con-troller | Sound level in room, dB(A), 10 m²-sab | Octave band centre frequency, Hz 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|---|---|
| Attenu-ated on side of terminal device | 25 | 60 | 51 | 45 | 40 | 38 | 38 | 41 | 44 |
| | 30 | 65 | 56 | 50 | 45 | 43 | 43 | 46 | 49 |
| | 35 | 70 | 61 | 55 | 50 | 48 | 48 | 51 | 54 |
| Unatten-uated | 25 | 57 | 47 | 37 | 29 | 25 | 22 | 21 | 21 |
| | 30 | 62 | 52 | 42 | 34 | 30 | 27 | 26 | 26 |
| | 35 | 67 | 57 | 47 | 39 | 35 | 32 | 31 | 31 |

The difference between the sound power level of the fan and the air flow controller (positions of adjustment agree to design pressure level and air flow) and the maximum recommended sound power level of the duct, by octave band, determines the sound attenuation requirement. In addition to the primary silencer of the fan, secondary silencers for the air flow controllers and to avoid "cross-talk" between rooms must be opted for when necessary. Further sound attenuation will not be necessary.

## 6.3 Pressure level in air ductwork

From the air flows in the room and the highest permissible sound level, the highest allowable differential pressures to the air flow controllers can be selected. The lowest differential pressure required is 50-100 Pa or the higher differential pressure required to control thermal disturbing forces /2/ which is determined according to the outdoor temperature

(-20°C), the height of the building and the air conditioning system. From the preadjustment of these differential pressures and air flows, the average pressure level for the ductwork and the highest permissible pressure losses for the air ducts can be determined, which should not exceed about half the average pressure level, Table 3.

Table 3. Aproximate depencence on pressure level of inaccuracy of preadjusted air flows.

| Inaccuracy of pre-adjusted air flows, % | PRESSURE LEVEL of air flow controllers |
|---|---|
| 10 | 5 • (pressure loss of ducts) |
| 20-30 | 2 • (pressure loss of ducts) |

The recommended pressure level of a variable air flow rate controller (maintaining a constant air flow rate when the pressure differential between high and low pressure sides varies) is the average of the highest and the lowest pressure differentials that are acoustically permissible. The pressure level of an ordinary damper (air flow rate controller, which change the air flow rate by modifying the resistance), is the same as its differential pressure with a design air flow and position of adjustment.

An upper limit for the pressure level of an air flow controller is usually imposed by its own noise generation or by the leakage noise of the ductwork and highest permissible sound level of the room, Figure 1. On the basis of the pressure level and the selected positions of adjustment, the air flows will balance by themselves with ordinary dampers, as in Figure 1. When variable air flow rate controllers are used, the inaccuracies of air flows are also often of the order of magnitude of Table 3.

From the pressure level of the ductwork, the air tightness requirements of the air ductwork are also worked out, to allow for control of leakage noise. Figure 2 /6/ shows an estimate based on field measurements /4/ and calculations /3/ of the sound power level generated by a flow of leaking air according to various air tightness classes. The air ducts should meet the requirements of air tightness class C /7/, Figure 3, if the flows of leaking air are not to cause an unreasonable noise nuisance.

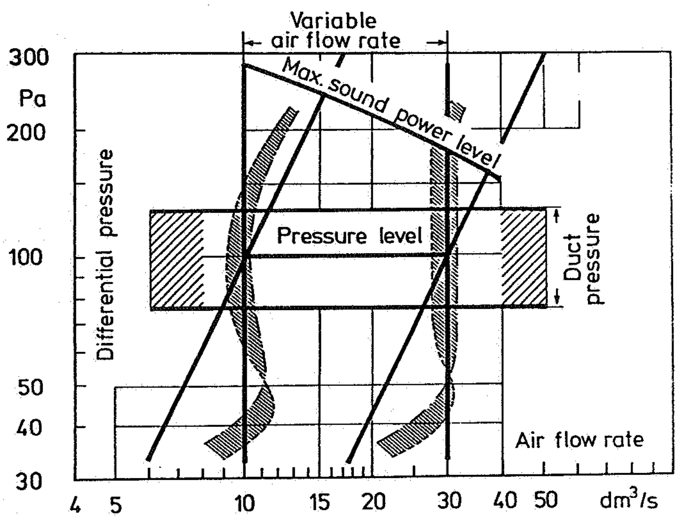


Figure 1. Air flows are determined on the basis of the positions of adjustment of various types of air flow controllers and on that of the selected pressure level. The sound level of the room is controlled when working below the maximum recommended sound power level.

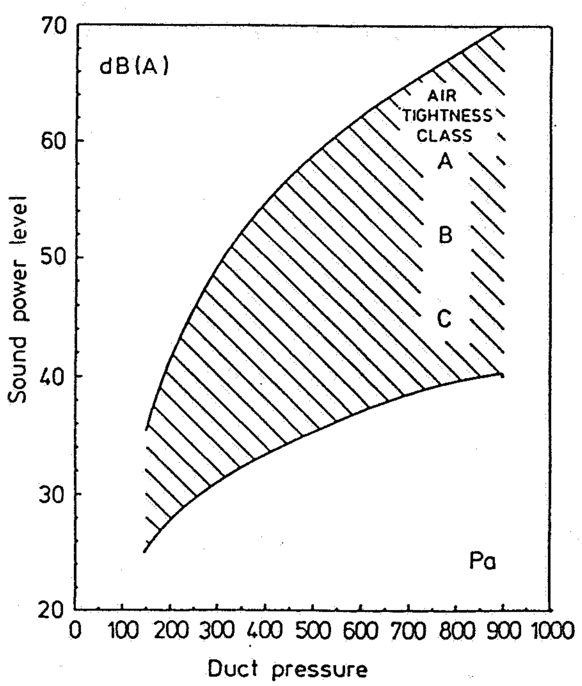


Figure 2. The estimated sound power level caused by air leakage in air ductwork system in various air tightness classes.

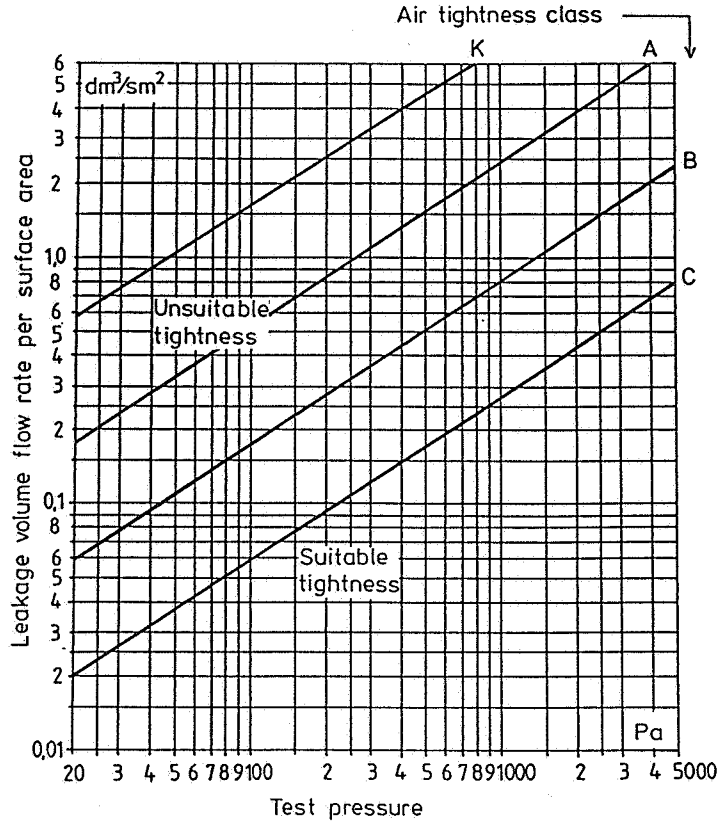


Figure 3. Air tightness classes for air ducts and central units according to Finnish regulations and guidelines.

<u>Air tightness class A:</u>

Visible ducts in a ventilated space.
Pressure difference relative to indoor air < 150 Pa.

<u>Air tightness class B:</u>

Ducts outside the ventilated space.
Ducts separated from ventilated space by means of covering panels.
Ducts in the ventilated space, pressure diffefence relative to indoor air > 150 Pa.

<u>Air tightness class C:</u>

Shall be applied as considered case by case:

- Ducts in high pressure systems.
- When duct leaks may produce pronounced adverse effects on the ventilation system operation, building air pressure conditions, indoor air quality or sound level.

<u>Air tightness class K:</u>

Enclosed air conditioners.
Equipment rooms and chambers for fans and other assemblies.

## 6.4 Choice of duct dimensions

The duct dimensions are selected according to highest air flow in the duct, from Figure 4. In branch ducts the maximum air flow is the same as the maximum air flow designed for the terminal devices. In the main ducts the maximum air flow need not always be equal to the sum of the maximum air flows of the individual rooms, but may be less. The dimension of the main duct is selected, where possible, on the basis of the sum air flow of the maximum air flows of the individual rooms or smaller than that by at most one duct size.

The demand controlled ductwork will work the better, the lower the duct velocities and the better the tightness of the ducts. In the limiting case of the maximum recommended duct velocity, it is always worth choosing the next larger duct size according to Finnish standard SFS 3282 /1/. Table 4 shows the favourable effects of such a choice as an approximate rule of thumb.

Table 4. Favourable effects of the choice of the next bigger duct size (Finnish standard SFS 3282 /1/).

| Quantity | Effects of duct size | Effects of next bigger duct size |
|---|---|---|
| Duct velocity | $v$ | $\approx \frac{v}{2}$ |
| Pressure loss | $\Delta p$ | $\approx \frac{\Delta p}{3}$ |
| Sound power level | $L_w$ | $\approx L_w$ - 7 dB |
| Leakage sound power level | $L_{wl}$ | $\approx L_{wl}$ - 8...-20 dB |

## 6.5 Estimation of pressure losses of ducts

Select duct velocities from Figure 4 on the basis of the highest permissible sound level for the room and the adjustability of the ductwork. A quick estimate of the pressure losses of the ducts can be made by counting the numbers of bends and branches. The average single local loss coefficient of the branches and bends is estimated as $\zeta = 1$. On the basis of the duct velocity,

Figure 4 indicates the magnitude of the single local loss. The sum of the single local losses thus calculated is regarded as the total pressure loss of the ducts. The friction pressure losses of the ducts are disregarded in dimensioning ducts.

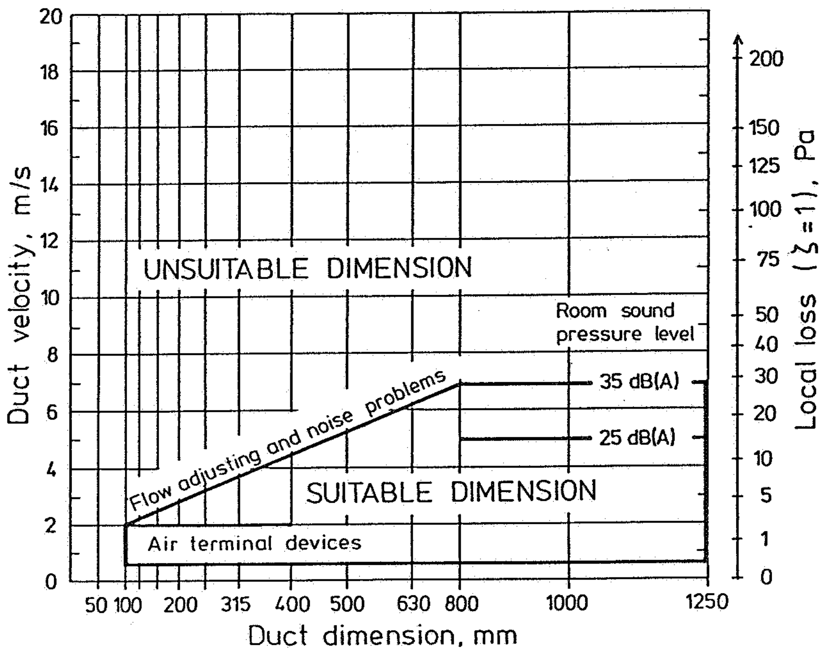


Figure 4. Recommendation for dimensioning of air ducts.

## 6.6 Adjusting and balancing of air ductwork

The traditional adjusting and balancing of an air ductwork which has been dimensioned overall is not required. A simple preadjusting and balancing can be made as indicated in Figure 5.

Checking of the preadjusting and balancing of a ductwork performed as simply as this will ensure that each room will get the air flows designed for it at the desired sound levels. If this does not occur, the ductwork is leaking too much or the pressures in the ductwork are not under control due to some other fault of implementation; or performance data supplied by the manufacturer for his equipment (air flow controllers and terminal devices, silencers, fans, etc.) is not valid, i.e. the quality level of the equipment does not accord with the stated values.

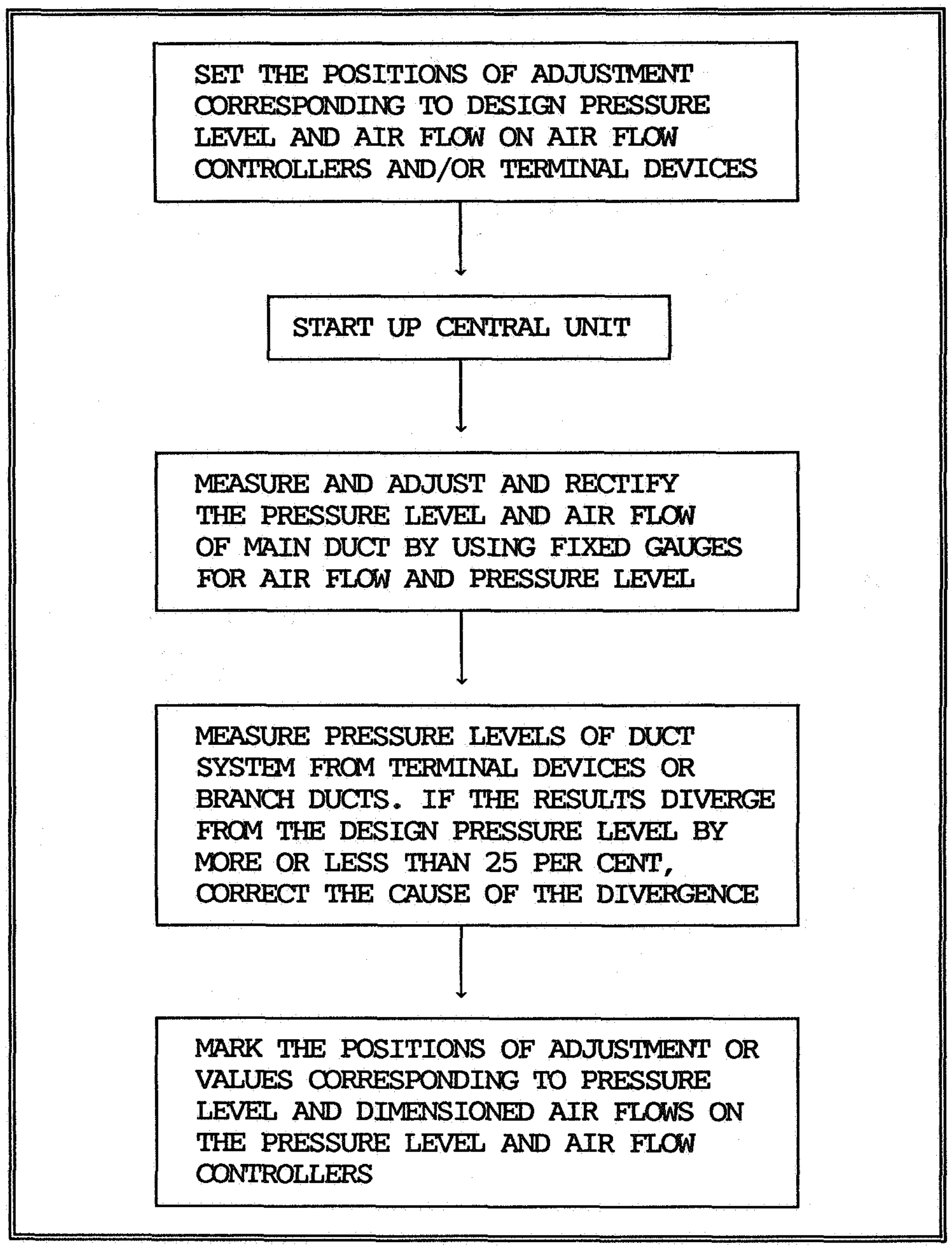


Figure 5. Checking of the result of preadjusting and balancing of air ductwork dimensioned in an overall manner.

## 7. CONCLUSIONS

A demand controlled ductwork should remain as symmetric as possible in terms of pressure losses in all variable flow conditions. The flow controllers should therefore have sufficient authority available for control, i.e. differential pressure relative to total pressure loss of the ductwork. Good flow and acoustical operating conditions should be created for the duct air flow controllers and terminal devices by means of the dimensioning of the ductwork. The noise of the fans must be attenuated by means of primary silencers, to comply with the highest permissible sound power level of the duct.

The standard of available technology determines the greatest permissible pressure losses in air ducts. Without silencers the present good duct air flow controllers and terminal devices can operate with pressure losses of at most 100-150 Pa, and the pressure losses of the ducts could thus be at most 50-75 Pa. The pressure losses of the flow controllers, attenuated with secondary silencers on the side of terminal device, could be at most 150-250 Pa, whereby the pressure losses of the ducts could then be at most 75-125 Pa.

When use is made solely of effective primary attenuation of the fan, the total pressure loss of the air ductwork should be a maximum of around 200 Pa. If use is made of flow controllers attenuated with secondary silencers on the side of the terminal devices, the total pressure loss of the air ductwork should be at most some 300 Pa. The air ductwork should meet the requirements of air tightness class C of the National Building Code of Finland /7/ if leakages are not to cause noise nuisance.

Supply and exhaust air fans of demand controlled ductwork should also be under control, for the flow controllers of the branch ducts cannot be used to change air flows in the central unit without causing a noise nuisance. The supply and exhaust air flows should be in control of each other so that the pressure relations of the building remain as desired.

## Acknowledgements

The Author wish to acknowledge the support of the Ministry of Trade and Industry, Finland (KTM).

## References

/1/ Finnish standard SFS 3282. Ventilation sheet metal ducts. Circular cross section. Connection dimensions. Helsinki 1980. Suomen standardisoimisliitto. 2 p. Finnish.

/2/ Heikkinen, J., Korkala, T., Luoma, M., Salomaa, H., Fault operations and susceptibility to disturbing factors of ventilation systems. Espoo 1987. Technical Research Centre of Finland VTT, Laboratory of Heating and Ventilating. VTT Research Notes 737. 127 p. + app. 25 p. Finnish, English abstract.

/3/ Holmberg, R., Laine, J., Fundamentals of noise control in airflow duct system. Espoo 1984. Technical Research Centre of Finland VTT, Labortory of Heating and Ventilating. VTT Research Notes 360. 98 p. Finnish, English abstract.

/4/ Holmberg, R., Laine, J., Spatiotemporal control of exhaust air ventilation. Espoo 1986. Technical Research Centre of Finland VTT, Laboratory of Heating and Ventilating. VTT Research Reports 425. 62 p. Finnish, English abstract.

/5/ Laine, J., Preadjusted air ductwork-realized! LVI-lehti 40(1988)11, Technical Appendix. pp. 3-7. Finnish.

/6/ Laine, J., Operation cost savings and noise reduction by the tightness of air ductwork. LVI-lehti 41(1989)6-7, Technical Appendix. pp. 6-10. Finnish.

/7/ National Building Code of Finland. D2. Indoor climate and ventilation in buildings. Regulations and guidelines 1987. Helsinki 1987. The Ministry of the Environment. 67 p.