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DEMAND CONTROLLED VENTILATION SYSTEMS FOR DWELLING HOUSES OF THE FUTURE

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1. INTRODUCTION

Many deficiencies have been observed in the functionality of ventilation in experimental building sites. In the case of ventilation systems with mechanical air extraction, the most typical of these shortcomings have been draughts, stuffiness, the diffusion of odours both from one dwelling to another and within individual dwellings, and condensation problems in the structures. Mechanical extraction ventilation systems are quite common in Finnish houses, being found in some 60 per cent of multi-storey dwelling houses. In experimental buildings equipped with mechanical air supply and extraction as well as warm air heating, the complaints are mainly concerned with noise, draughts, the diffusion of odours from one dwelling to another and problems related to the use and maintenance of the systems. Less than 10 per cent of the Finnish housing stock is equipped with both mechanical air supply and extraction.

An extensive field study on the operation of ventilation in domestic dwellings and its requirements in terms of health and comfort (Ruotsalainen et al. 1990), which included 251 buildings. The sample consisted of both detached or semi-detached houses and blocks of flats. Three different types of ventilation systems were included.

The mean ventilation rates measured during a two-week period varied remarkably from 0.1 to 1.5 ach across the sample. The average was 0.52 ach including also the ventilation caused by the airing. The differences between the ventilation systems were small. However, the ventilation rates were on average smaller in houses than in apartments. Especially stuffyness and dryness of the bedroom air were problems in the residences. Almost half of the occupants felt the bedroom air in the mornings to be at least sometimes stuffy. 40 % of the occupants felt the bedroom air to be usually too dry. Humidifiers were used in over one third of the risidences. The dissatisfaction with the humidity increased considerably, when the relative humidity was below 40 %.

The occupants of the apartments reported systematically more symptoms and environmental complaints than the occupants of the houses. In the houses the symptoms and environmental complaints were more common among the occupants with natural ventilation than with balanced ventilation. In the apartments with balanced ventilation the occupants reported more symptoms and complaints than those with natural ventilation.

In experimental buildings it has also been observed, for instance, that the dual-speed systems typical of multi-storey buildings do not correspond to people's living habits, and that it must be possible to exercise both temporal and spatial control over the ventilation system. At the very least, occupants must be able to increase (accelerate) the rate of extraction or fresh air in spaces exhibiting a large variation in the production of air-borne impurities. Such premises are the kitchen, the bathroom and the WC.

Housing and ventilation have also been examined theoretically from the social psychological standpoints (Anttila 1990). In an analysis of the comfort of the occupants, a principle of minimum functionality for ventilation was outlined.

The principle is based on the requirement that ventilation should function satisfactorily even if the occupants themselves do not actively be engaged in the control of the ventilation. The occupants would nevertheless be able to regulate the ventilation themselves. The minimum functionality principle also won favour among the residents of the Turku housing-exhibition estate.

The functional and technical requirements which have been set for ventilation systems in dwelling houses of the future will result in ventilation systems featuring trouble-free and demand-controlled operation (Luoma, Kohonen 1988). This paper discussed the functional requirements and technical solutions of such ventilation systems.

2. FUNCTIONAL REQUIREMENTS

The most important functional requirements for ventilation systems in dwelling houses of the future are that:

- an occupant should have the ability to operate the ventilation according to his/her needs
- the ventilation system should not be sensitive to external disturbances
- the efficiency of the ventilation in living spaces should be high
- the ventilation system should be economical in terms of energy consumption and should also be reliable
- subsequent modification of the quality standard should be possible.

Demand controlled operation and accelerating of ventilation

With airflows complying with Finnish Building Code, the ventilation of small dwellings in particular may be unnecessarily great. Conversely, the ventilation in some of the rooms of large dwellings may occasionally be inadequate. In spaces where ventilation-loading factors vary a great deal (such as in the kitchen and the bathroom), the ventilation may be unnecessarily great most of the time and yet inadequate on the occasions when the load level is high. The problem applies to systems in which the airflows are constant. At the present time there are no clear principles on which to base the airflow ranges of demand controlled ventilation. Generally speaking, demand controlled ventilation rate may be greater or smaller than that prescribed in the regulations.

The necessary level of ventilation is determined according to the factors that load the ventilation. On the basis of load data and criteria from the literature, Saari (1990) has used the Monte-Carlo simulation to determine numerically the airflow ranges suitable for various rooms and various load situations in living spaces (Table 1).

The basic requirement for ventilation is that it should be sufficient to remove the impurities emitted by the materials of the building structures. Moreover, the ventilation of an unloaded room must not fall below the values of the basic norm even in the event of air extraction being increased in some other room space.

It should be possible to control the accelerating of ventilation both temporally and spatially. In such circumstances it must be possible to increase the air extraction so that a marked effect will be achieved.

It should also be possible to increase an air vent's airflow from the basic level by at least 50 per cent. There should not be unequal effects among the various dwellings, which should experience an approximately even increase in the airflow. When the extract airflows are increased, it is also necessary to ensure that there will be an adequate supply of outdoor air. The pressure difference over the external walls may not exceed 30 Pa, which tends to limit the magnitude of the increased extract airflow.

In addition to air vent-specific accelerating, there may also be a need to increase the airflows in individual dwellings, e.g. when cooling with outdoor air. In advanced systems there must also be the facility to accelerate the air extraction in more than one room, not only in "dirty" spaces but also in bedrooms and living rooms.

Controlling thermal forces and the effects of wind

The ventilation system should function well in all weather conditions. The most important disturbance factors are wind and boyance effects arising from temperature differences. The control of thermal forces can be influenced by selection of the air pressure in the ducts, the airtightness of the building envelope and the operating pressure difference of the fans. The criterion is that the uppermost floors of a multi-storey building should have a negative pressure even in conditions of severe frost (-20 ... -30°C).

Correspondingly, the criterion for the effects of the wind is that there should be no air infiltration into a dwelling even in a high wind (10 m/s). The airtightness of the external walls is of critical significance to the air infiltration. The airtightness of the external walls should be at least $n_{50} = 0.5\ dm^3/s$. By contrast, the effect of the airtightness characteristics of other structural components and of the pressure difference of the air vents on air infiltration is minimal. A suitable ratio of supply to extract airflow rates is about 0.8.

The internal airtightness of the building is also of considerable importance as far as the control of ventilation is concerned. The airtightness of ducts and the walls between individual dwellings and between the dwellings and the staircases should be specifically ensured. The system should also be insensitive to the opening of windows and doors.

The calculated values for the airtightness characteristics of structures necessary in order to control pressure conditions are (Karvonen, Luoma 1990):

- a pressure head of 50-100 Pa should be available for the air vents
- air leakage through external walls at a pressure difference of 50 Pa should be less than 0.5 dm^3/s
- air leakage through intermediate floors at a pressure difference of 50 Pa should be less than 0.1 dm^3/sm^2
- air leakage through a closed dwelling door at a pressure difference of 50 Pa should be less than 2 dm^3/s.

Modification and improvement of the quality level

Modifications are generally a question of improving the level of quality at a later date. The following improvements may come into question: provision of mechanical air supply, filtering of supply air, provision or expansion of the facility to accelerate air extraction, heat recovery, reduction of the noise level and measures concerned with aesthetic aspects.

Various design solutions can be employed to allow for future improvement of quality level. Wide dimensioning of the ductwork will make it possible to increase the airflows. Extract ducts for individual dwellings will allow the use of dwelling-specific units and thus the control of dwelling-specific airflows. Ducting supply air into the building facilitates centralized filtering and mechanical blowing. Figure 1 shows an example of an air conditioning system, whose quality can be improved.

Thermal comfort and energy economy

It has been observed in experimental buildings that draughts generally occur in constant airflow systems based on air extraction when there is no control exercised over the supply air. Moreover, the supply air inlets easily cause draughts in the wintertime.

The ASHRAE standard 55-1981 defines the limits for the maximum rate of operative temperature change, for the steady drift rate and for the maximum amplitude during rapid temperature fluctuation. According to the standard, the operative temperature may drift if the rate of change is less than 0.6°C/h. The temperature may vary with an amplitude of less than 1.1°C, but if the amplitude exceeds 1.1°C, the rate of change must not be greater than 2.2°C/h. The standard can be applied to a rising temperature trend. There is no equivalent standard for a declining trend. The effects of falling temperature on comfort have also been investigated, but the results of the various studies are contradictory.

In a dwelling house a temperature of +18°C may be regarded as the minimum acceptable room temperature. In order to ensure that the temperature does not fall below +18°C in the accelerated ventilation mode during the heating period, e.g. increasing of the airflows in a bedroom at night, the higher heating load must be taken into account in the design of the heating system.

When the air inlets are installed above the radiator, the cold air will not flow to the floor level immediately. On the other hand, to prevent through-flow, it would be better to try and use only one wall for the positioning of the outdoor air inlets.

In supply and extraction ventilation systems the distribution of the air in the room can be designed to prevent draughts even when the ventilation rate is high. The maximum is about 4.0 dm^3/s, which is based on a study by Sandberg (1987).

Although the priority of energy cost is not very high at the moment, energy economy is also a goal when systems are being developed. The object is that a variable airflow system must not consume more energy than any system designed in accordance with the present building regulations. That is no problem, since the energy consumption of demand controlled systems is lower than that of conventional systems.

Operational availability

The availability of a system is described using the following criteria:

1. Usability expresses the ability of the system to function without downtime or breakdowns.

2. Operational reliability expresses the ability of the equipment to function without the occurrence of a defect for a required period of time.

3. Ease of maintenance expresses the facility for returning defective equipment to serviceable condition as a consequence of maintenance measures. In many cases ease of maintenance is more important than operational reliability from the standpoint of its availability. It would seem reasonable that a defect might occur in a system once a year but, if it were to take 11 months to repair the fault, its availability (in this case the ease of servicing) could hardly be considered satisfactory.

4. Maintenance reliability expresses the ability and readiness of the maintenance organization (spare parts, tools, personnel, documents, etc.) to repair and maintain the system or a component device.

In availability analyses the biggest problem with extraction ventilation systems proved to be how to take outdoor air without causing draughts. In the case of outdoor air vents, there are significant shortcomings in production, design, installation and operation. The task of replacing the filters in outdoor air vents is generally left to the occupants themselves. This calls for operating and maintenance instructions clearly explaining the need to change the filter. If the air vent has various control settings, it must be possible to lock them in place, and while the filter is being replaced, they must not deviate from the previously selected settings. It must also be possible to lock the control settings of extract air vents, so that they cannot be intentionally or unintentionally changed.

In supply and extraction ventilation systems there is an obvious need for greater automation in both the ventilation unit and the flow controllers for dwellings. Measuring and alarm points will be necessary, especially in the case of volume flow, freezing and melting. The opportunities for versatile operation emphasize the need for clear instructions concerning use and maintenance.

Compatibility with the component system building technique

The future way of construction will feature the characteristics of low density housing, with the emphasis in multi-storey buildings placed on good sound proofing between dwellings, ventilation control for individual dwellings, and low-rise construction. The TAT (Totally Adaptable Technology) component building system (Sarja 1990), which emerged as a result of a development project for office and residential buildings, is a hierarchical, module-based, open system for the design and construction of residential and office buildings. The system comprises architectural principles, a space system, compatible and integratable technical subsystems, and a dimensional and tolerance system. The TAT building system is based on the industrial production of building parts and components. The assembly of the buildings and the systems takes place at the work site.

The ventilation system is one of the technical subsystems of a building, and its construction has been adapted to the concept of industrial construction. In practice, this means that there must be a certain range of compatible, industrially manufactured components from which the desired ventilation system can be assembled.

The hierarchical levels of the TAT system are the building, the sub-building, the module and the component.

The technical components of the ventilation subsystem are the air-handling unit, the duct, the flow controller, the terminal unit and the control unit. Depending on standard of quality, the components include various functions. Air-conditioning systems can be divided into four different categories on the basis of the decentralizing principle.

3. DESIGN PRINCIPLES

In the LVIS-2000 research program's project "Ventilation systems for dwelling houses of the future", only three types of system were examined:

- (centralized) air supply and extraction system for individual sub-buildings
- air input and extraction system for individual dwellings

- air supply systems for individual dwellings and air extraction systems for individual sub-buildings (centralized air extraction systems).

The most important technical criteria in the design of ventilation systems are:

1. A basic ventilation rate of 0.35 dm^3/sm^2 is implemented in all room spaces in all circumstances

2. The airflow of an air vent in the accelerated mode should be 50 per cent greater than that of the normal operation mode

3. 25 dm^3/s is the greatest airflow through any single air vent (because of the noise)

4. The pressure difference across the air vent must not be greater than 100 Pa (because of the noise)

5. Increased airflows must not raise the pressure difference across an outside wall above 30 Pa

6. The building must not have a positive pressure difference

7. In order to avoid excessive energy consumption, the overall airflow in the dwelling may be raised by a factor of two at the most

8. Energy consumption may not be greater than would be the case if a system made in accordance with the Finnish Building Code were to be used.

The slower the airflow velocity in the ducts and the more airtight they are, the better is the functioning of ductwork. Numerical flow and noise models have been combined with actual measurements to determine the maximum permissible airflow velocity in the ductwork and its maximum permissible noise levels on the basis of the highest noise level in the room (Laine 1989). By also taking account of the pressure losses permissible in the ductwork in order to achieve an adequate level of controllability, the set of dimensioning curves for ductwork shown in Figure 2 is obtained.

Without noise nuisance, a pressure level of 100-150 Pa can be achieved using good modern control and terminal equipment. In that case the highest permissible pressure loss of the ductwork would be 50-75 Pa. One could then "standardize" the operationally optimal total pressure loss of the ductwork at 200 Pa. In order to be able to implement temporal and spatial control of the ductwork, the pressure level of the control and terminal equipment should be about 100 Pa. In addition, fans should be controlled separately because it is impossible to influence the total airflow of the air-conditioning unit without noise nuisance by using the control and terminal equipment of branch ducts.

The air-conditioning plant's airflows, pressures and noise levels cannot be controlled unless the ductwork is airtight. Good ductwork should always meet the Building Code's air tightness class C, i.e. 0.1 m^3/sm^2 at 250 Pa pressure difference.

When using a fan with a slightly sloping curve, the required pressure difference above the flow controllers is small or pressure controllers are entirely unnecessary. Ductwork control based on a slightly sloping fan curve is highly suitable in situations where the total airflow control range is 50-100% of the maximum airflow.

The technical prerequisites for accelerating the total airflow using various fan control methods have been examined numerically (Haikarainen 1990), (Table 2).

We can see from the table that, using the constant pressure control, the total airflow can be tripled without raising the pressure level of the ductwork. At the same time it is estimated that if dwellings increasing the airflows make up 30% of the total number of dwellings, then one dwelling's supply and extract airflows can be raised to more than 7 times the basic operation mode. Increasing the airflow sevenfold will not succeed unless the ductwork within the dwelling is made very wide and the room air vents are allowed a sufficient pressure difference. Correspondingly, if the ductwork is dimensioned such that the basic airflow has a friction pressure loss of less than 0,5 Pa/m and the room air vent pressure loss is at least 75% of the usable pressure loss for the dwelling, then one room's airflow can be quadrupled.

Room temperature behaviour during accelerated ventilation

Room temperature behaviour during accelerated ventilation mode has been examined using dynamic system simulation (Haikarainen 1990). The systems under examination featured extraction ventilation with heating from radiators of varying output capacity. Another heat distribution method which was examined was combined radiator and floor heating. Figure 3 gives an example of the results of the simulation.

The results of the calculation show that radiator size does not affect temperature control speed when using a thermostatic radiator valve. Using radiators of varying output capacity, the drop in room temperature after the accelerated ventilation had been started was just as much during the first ten minutes. A decrease in room temperature nevertheless causes an increase in radiator output about one hour after the accelerating has begun, at which time radiator output and room temperature are, practically speaking, in a steady-state condition.

If ventilation is accelerated for a longer period of time, then the radiator should be dimensioned on the basis of the maximum airflow so that the room temperature remains at its set value. In circumstances of short-term ventilation increase, an over-sized radiator will not produce the maximum output if a thermostatic radiator valve is used. On the other hand, ventilation increase is generally accompanied by internal heat loads which compensate for the increased output requirement.

The maximum ventilation rate presented by Haikarainen is based on maintaining the room's thermal comfort during accelerated ventilation such that the number of those dissatisfied with the temperature conditions in the space rises to no more than 20% with the PPD at a basic level of 10%. In such circumstances the room temperature may drop by no more than 2.5°C and the average radiation temperature should remain almost constant. Airflows are determined on the basis of an outside design temperature of -27°C.

In a dwelling-specific system it is difficult to assess the draught because, when the extract airflow is increased during accelerated operation, a greater flow of outdoor air enters the room, to some extent uncontrollably, in the form of air leakage.

If a dwelling-specific ventilation unit were to be equipped with an adjustable heater and the supply airflow were to be increased at the same time as the extract airflow, then it would be possible to increase the airflows in the same way as in a supply and extraction ventilation system.

For instance in room space with a volume of 50 m^3 calculated in accordance with a specific ventilation rate of 0.5 dm^3/s is:

$$q_{io,h} = 0.5 \times 50/3.6\ dm^3/s = 6.9\ dm^3/s$$

Based on the studies by Haikarainen the basic airflow, the maximum airflow at an outdoor temperature of -27°C is obtained:

- on the basis of the ductwork of the supply and extraction ventilation system

  $4 \times q_{io,h} = 27.8\ dm^3/s$

- on the basis of thermal comfort in the extraction ventilation system

  $0.5 + 1.0\ dm^3 \rightarrow 20.7\ dm^3/s$

- on the basis of the ductwork in a dwelling-specific ventilation system

  $4 \times q_{io,h} = 27.8\ dm^3/s$

In an extraction ventilation system, a prerequisite for a fresh airflow of 20.7 dm^3/s is that there are at least 4 outdoor air vents in the room, because modern outdoor air vents enable a draughtfree airflow into the room space of no more than 6 dm^3/s per air vent when the outside air temperature is at or below 0°C. In a dwelling-specific system an airflow of 27.8 dm^3/s is too great if the temperature of the supply air is permitted to be below +16°C.

4. SYSTEM DESCRIPTIONS

4.1 CENTRALIZED SUPPLY AND EXTRACTION VENTILATION SYSTEM

Operating principle

A centralized air supply and extraction ventilation system (Figure 4) serves dwellings situated no higher than on the sixth floor. The size of the ventilation unit then remains reasonable and pressure differences in the building and the ventilation ductwork are controllable.

The ventilation system can be employed in three different ways. During a long period of absence, the ventilation of the dwelling can be centrally switched to the reduced level, which is lower than that of normal use.

In normal use, room-specific ventilation is accelerated through the supply and extract air vents. Thus the occupant can handle the accelerating on a demand controlled basis.

The airflow is doubled or trebled by readjusting just one air vent at a time. The extract airflow can be accelerated in the kitchen, washroom and WC as well as in the living room and bedroom. The supply airflow can be accelerated in the living room and bedroom. A readjusted air vent reverts to the basic setting in "dirty" spaces but not in living rooms and bedrooms. More over, the total airflow of the dwelling can be raised to the ventilation rate necessary to achieve a marked cooling effect.

The hallway's supply airflow corresponds to the extract airflow from "dirty" spaces. There are coupled supply and extract air terminal units in living rooms and bedrooms, so that an increase in the supply airflow also raises the extract airflow at the same time.

Ductwork and terminal unit

Within the dwelling, the extracts from different rooms are connected to the same duct. Each dwelling is fitted with one supply and one extract duct, so that the dwelling's total airflows can be controlled. The dwelling's air supply and extract ducts are fitted with closeable fire screens. The dwellings' air supply and extraction ducts are connected to sub-building-specific supply ducts. The ductwork is widely dimensioned.

Air-handling unit

The air-conditioning unit is designed so that dwelling-specific flow controllers and air vents can use a pressure difference of 100 Pa. The air-conditioning unit operates on a constant pressure principle. Basic and cooling situations are achieved by the use of dwelling-specific flow controllers.

Operation during accelerated ventilation mode

The system can be dimensioned so that when the ventilation is being accelerated, the dwelling's total airflow either increases at almost the same rate as that of the readjusted air vent (additional principle), increases to some degree, or does not increase significantly at all (borrowing principle). Different alternatives are implemented through the dimensioning of the dwelling-specific flow control device.

Calculations indicate that it is advantageous if the pressure loss of the air vent is at least half that of the available pressure loss (Table 4). In high-rise residential buildings, drawbacks arising from thermal forces can be diminished by controlling the air inlet devices on lower floors on the basis of the outside temperature.

4.2 DWELLING-SPECIFIC SUPPLY AND SUB-BUILDING-SPECIFIC EXTRACTION VENTILATION SYSTEM

Operating principle

A mechanical extraction ventilation system, which makes use of a common extract duct system, serves dwellings located on six successive floors, and a mechanical extraction ventilation system, in which there is dwelling-specific ducting, correspondingly serves dwellings located on four floors. The extraction unit then remains reasonably sized and the pressure differences in the building and in the ventilation ducts are controllable.

In an air extraction system, the ratio of supply to extract airflows in individual dwellings does not need to be kept so precisely constant as in a centralized supply and extraction ventilation system. Consequently, there are a number of different ducting principles (Figure 5).

The occupant can accelerate the extract airflow as the need arises. A readjusted air vent should return automatically to the normal setting, but it can also be locked on the accelerated setting.

Terminal units

The extract airflows of individual terminal units are given in Table 5. The kitchen airflow in the accelerated mode is a minimum of 20 dm^3/s and a maximum of 42 dm^3/s.

Noise insulation between dwellings is handled by noise dampers in either the terminal unit or the rising ducts.

Ductwork

In a building-specific extraction system, the rising ducts of the kitchens and those of the bathrooms and clothes closets are connected to a connection box before the extract fan. In dwelling-specific extract ductwork, the dwellings have their own rising ducts which are similarly connected to a connection box before the extraction fan. The connection box is dimensioned so that the flow rate is less than 4 m/s. In the normal operation mode the terminal unit's pressure head is 80-120 Pa.

Extract unit

The extract unit consists of noise damper, extract fans and a pressure controller. The static pressure produced in the duct by the extract unit is no more than 1.5 times the air vent's pressure loss in the normal situation. The sound level caused by the extract fan in the duct should not exceed the values given in Table 6, if there is no damper in the terminal unit. The fan always requires separate noise damper.

An extract fan having a slightly sloping fan curve is selected so that the pressure difference in the duct falls by no more than 10% from value of the normal mode when accelerating is in progress. Pressure control based on a slightly sloping fan curve is highly appropriate when the total airflow increase is not very great (e.g. less than 100%).

In two-step pressure control, a pressure switch increases or decreases the speed of rotation on the basis of a pressure sensor reading. Each control phase operates for at least half an hour. Two-step pressure control is suitable in a situation where one wants, for example, to double or treble the airflow. The change in the fan rotation speed should be quite small (e.g. less than 30%).

In constant pressure control, a separate arrangement is required to maintain constant pressure (a setting of 100 Pa, for instance) in the duct. Constant pressure control is suitable for a large range of ventilation rates.

4.3 DWELLING-SPECIFIC SUPPLY AND EXTRACT VENTILATION SYSTEM

Operating principle

A dwelling-specific ventilation system is particularly well suited both to low and high-rise residential buildings. The use of dwelling-specific ventilation and separate stairwells makes it possible to avoid the spread of smells and dampness from lower to higher floors, which is a problem especially in high-rise buildings. There are various alternatives for ventilation units and extract ducting.

The occupant can increase the total extract airflow of a dwelling as the need arises. When the total airflow is being increased, the fan switches to a faster rotation speed. The airflow can also be increased in individual rooms, e.g. in the kitchen and bathroom. In such circumstances the ventilation system operates on the borrowing principle. The dwelling has a heat recovery unit which is always equipped with a supply fan. The extract fan can be located in the dwelling or on the roof of the building.

Conveying extract air out of the building

The ducting of extract air is an important aspect in the case of an apartment building equipped with dwelling-specific ventilation.

Table 6 shows the problems associated with various alternatives and ways in which they may be solved technically. Smells can spread into the dwellings from positive-pressure duct in structural cavities. Noise as well as condensation problems are also associated with several alternatives.

After heat recovery it is not economic to convey extract air inside structural cavities because the extract air then heats up again. If cold extract air is conveyed outside structural cavities, there is then the danger of condensation and freezing. These difficulties can be avoided by blowing the extract air straight out through the wall.

When expelling extract air directly, its initial velocity should be high (e.g. 10 m/s) so that the wind and the temperature difference between the extract and outdoor air does not divert the jet back onto the building envelope. The outdoor air intake and the air expulsion unit are positioned on different walls.

Terminal units and airflows

Extract airflows per air vent are given in Table 7. The smaller airflow range applies to the normal situation and the larger to accelerated operation.

In a mechanical supply and extraction system, the intake of outdoor air is planned according to Part D2 of the Finnish Building Code in order to ensure that supply airflows are adequate. In the normal situation the supply airflow is 80% of the extract airflow.

The handling of the noise insulation between dwellings depends on the extract ducting solution employed. If a common extract duct is used, the noise insulation is achieved either by using a noise damper located in a terminal device or by adhering to Part C6 of the Building Code.

Ductwork

The airflow velocity in a dwelling duct should be less than 3 m/s. In the normal situation, the average pressure loss of the terminal unit is 50 Pa. The outdoor air duct is insulated against heat (100 mm) and dampness if the duct is located in a warmer space.

6. DISCUSSION

In the LVIS-2000 research programme, alternative system solutions are sought for the control of energy use and indoor climate conditions in buildings of the future. The starting point for the development project concerned with ventilation systems in residential buildings was that the occupant is regarded as the ventilation system user. In a study which approaches occupant activity from a socio-psychological standpoint, dwelling ventilation developed on the minimum functionality principle functions satisfactorily without the occupant playing any active role. On the other hand, the occupant is in a position to regulate the ventilation if he so desires. The occupant is indifferent as to what kind of ventilation system is used to produce a good indoor climate.

The minimum functionality principle can be technically implemented using a variable airflow ventilation system. Other objectives were set for the variable airflow system besides the facility of accelerating the ventilation. The system should not be susceptible to external interference factors. Ventilation efficiency should be good, especially in living spaces. The system should be economically efficient with regard to energy. It should be possible to modify the system at a later date.

In the development project associated with industrial component construction, the ventilation systems have been classified according to the decentralization principle and operational functions. From this extensive classification, three system types were selected for examination and they are the centralized supply and extraction system, the centralized extraction system and the dwelling-specific ventilation system. Natural ventilation systems were not examined.

At present the most important component used for accelerating a dwelling ventilation system is the cooker hood. The cooker hood should satisfy the following operating requirements: in the basic situation the airflow should be small and pressure difference great (e.g. 6 dm^3/s and 80 Pa). During accelerated operation mode the airflow should be greater and pressure difference smaller (20 dm^3/s and 40 Pa).

On the basis of a price comparison of ventilation systems, a mechanical supply and extraction system or a dwelling-specific system is 100-300 FIM/m^2 more expensive than a mechanical extraction system. The dwelling-specific system has the lowest annual energy and operational costs.

In this project it has been assumed that variable airflow ventilation systems will be controlled manually. Automatic control can also be arranged. At present it seems that CO_2-, moisture and air-quality sensors will be used. It is difficult to justify the need for a CO_2-sensor to the occupant as moisture removal is generally not a problem in Finland's climate, and air-quality sensors are, for the time being, unreliable.

The ventilation concepts introduced in this paper have already found their applications in practice. Three demonstration dwelling-houses are under construction and a product development has just started (Luoma, Laine, Kohonen 1990 and Luoma 1990).

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TABLES

MEAN AIR EXCHANGE RATES FOR APARTMENT	
- material emission loads	0.1 - 0.5 1/h
- humidity loads	0.1 - 0.4 1/h
- heat load (in summer)	1.0 - 3.0 1/h
AIR FLOW RATES FOR DIFFERENT LOADS	
Sleeping rooms	
- human based odours,	
• at night	4 dm^3/s, person
• daytime	8 dm^3/s, person
Living rooms	
- human based odours,	
• normally	4-8 dm^3/s, person
• visitors	8 dm^3/s, person
Kitchen	
- humidity loads,	
• during use	15-40 dm^3/s
Bathroom	
- humidity loads,	
• during shower	50-100 dm^3/s
• bath	20-30 dm^3/s
• washed clothes drying	10-20 dm^3/s
Sauna	
- humidity loads,	
• during use	4 dm^3/s, person (≈5-10 1/h)
Toilet	
- removal of odours in 10 minutes	20 dm^3/s
Clothes closet	
- material emission loads	0.5 - 1.5 1/h
Smoking	
- odours of smoking	20-40 dm^3/s, smoker

Table 1. Demand controlled ventilation rates for various room spaces (Saari 1990)

CRITICAL FACTOR / SYSTEM	FAN 1=constant pressure control 2=two-steps fan control 3=slightly sloping fan curve	Ductwork R<0,5 Pa/m	Control of supply air coil	Thermal comfort	Draught
Supply and extract	1 : 9 x $q_{i0,h}$	4 x $q_{i0,h}$	12 x $q_{i0,h}$	No limitations if $T_{supply} \geq +16°C$	n_{max} 4,0 1/h
Extract - water radiator heating - water radiator and floor heating	2 : 7 x $q_{i0,h}$ 3 : 4 x $q_{i0,h}$	4 x $q_{i0,h}$		$n_{max} = n_0 +$ 1,0 1/h 1,2 1/h	maximum fresh air flow rate 6 dm^3/s per air vent
Dwelling-specific	3 : 2-10 x $q_{i0,h}$	4 x $q_{i0,h}$		like above	

Table 2. Greatest allowed total airflow acceleration based on different criteria.

Mode	Flow rate
Standby	< 0,35 dm^3/sm^2
Normal	0,35-1,0 dm^3/sm^2
Cooling	0,50-1,5 dm^3/sm^2

	Air flow, dm3/s	
Space	Supply	Extract
Bedroom	5	6
Livingroom	6	8
Kitchen		8
Bathroom		8
Toilet		5
Clothes closet		3
Hall	(K + BaR + WC) x 0,8	

Table 3. The modes of use and airflow ranges (dm^3/sm^2) of the centralized supply and extraction ventilation system.

Pressure diff.		Air vent position	Increase in the total air flow %
Air vent Pa	Flow controller Pa		
75	25	1 → 2	62
75	25	1 → 3	82
50	50	1 → 2	32
50	50	1 → 3	38
25	75	1 → 2	13
25	75	1 → 3	15

Table 4. Dependency of total and air vent-specific airflows on the usable pressure head between the terminal unit and flow control device.

	Common ducting	Individual ducting
Space	Flowrate dm^3/s	Flowrate dm^3/s
Kitchen	13 - 20	6 - 20
Bathroom	15	15
Toilet	10	10
Clothes closet	3	3

Table 5. Air vent-specific airflows.

Space	Flowrate dm^3/s
Kitchen	6...8 - 20...30
Bathroom	5...8 - 15...20
Toilet	10...12
Clothes closet	3...5

Table 6. Extract airflows per air vent.

FIGURES

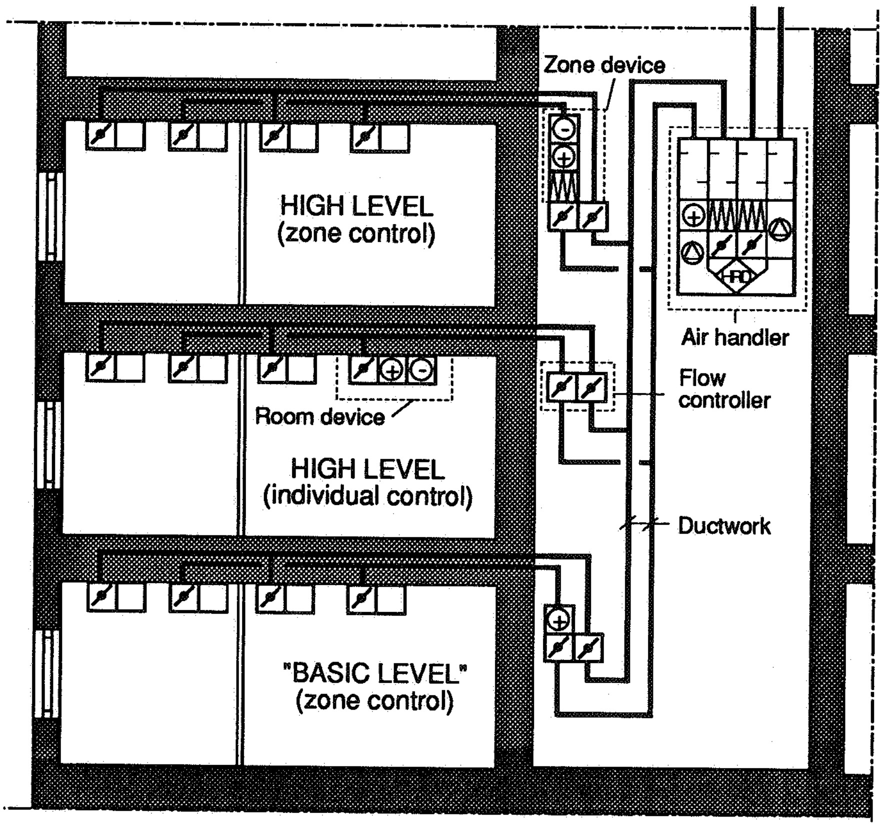


Figure 1. Air conditioning system, whose quality can easily be improved.

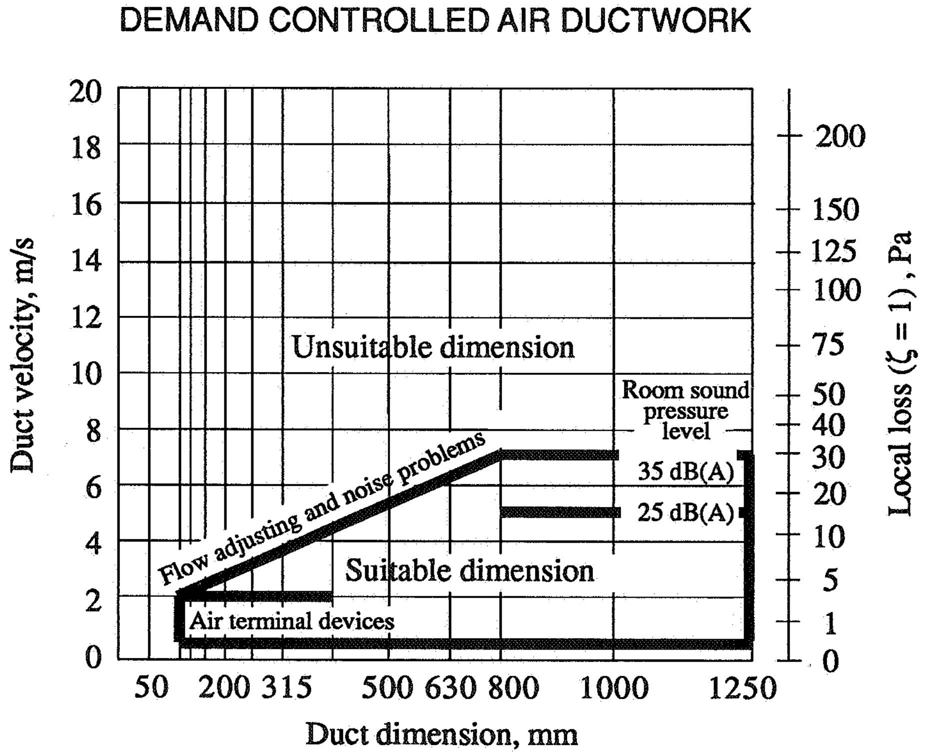


Figure 2. Set of dimensioning curves for ductwork.

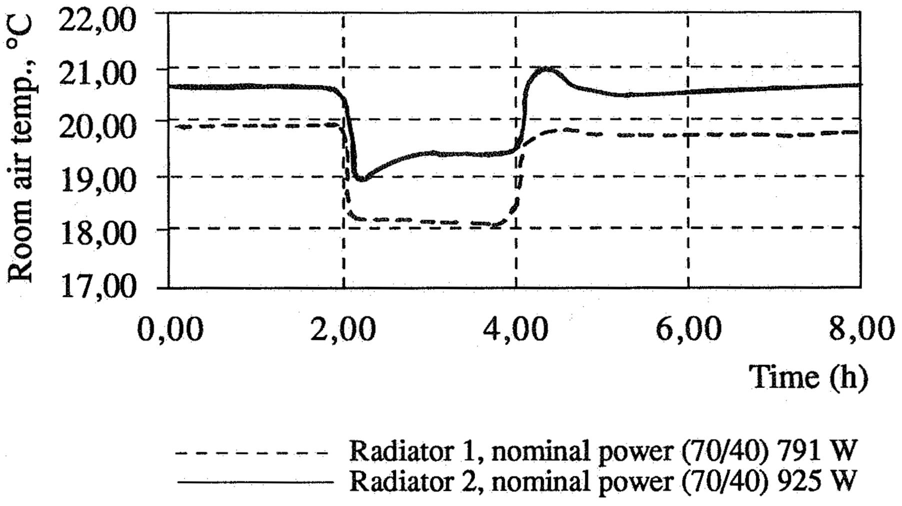
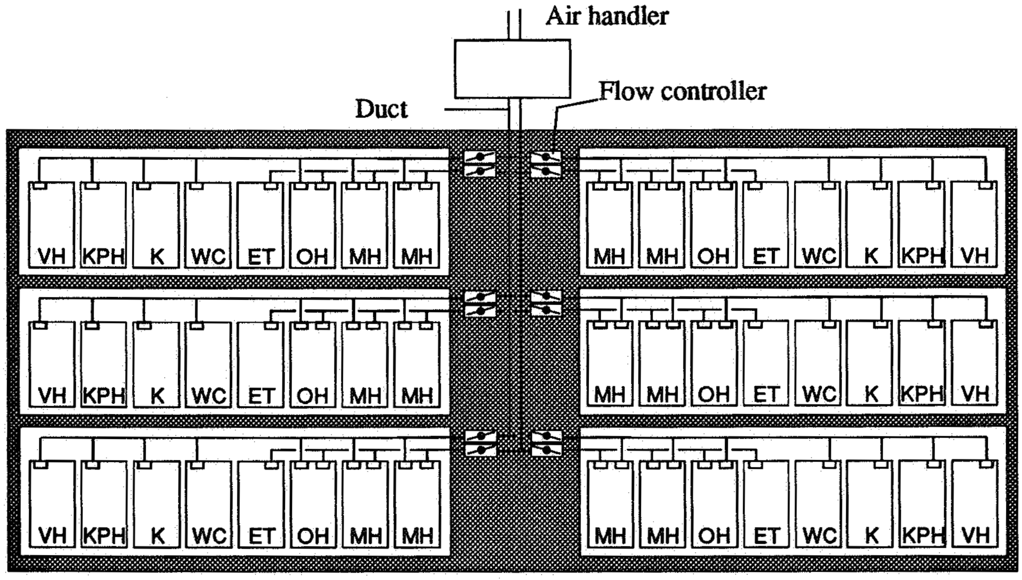


Figure 3. Room temperature when the space is equipped with one water radiator. The extract airflow in the space changes to 6.6 dm^3/s at moment 2:00 and then reverts to the original value at moment 4:00. The outside temperature os -27°C and the return water temperature is +70°C.



VH = Clothes closet
KPH = Bathroom
ET = Hall
K = Kitchen
OH = Livingroom
MH = Bedroom

Figure 4. A centralized supply and extraction ventilation system.

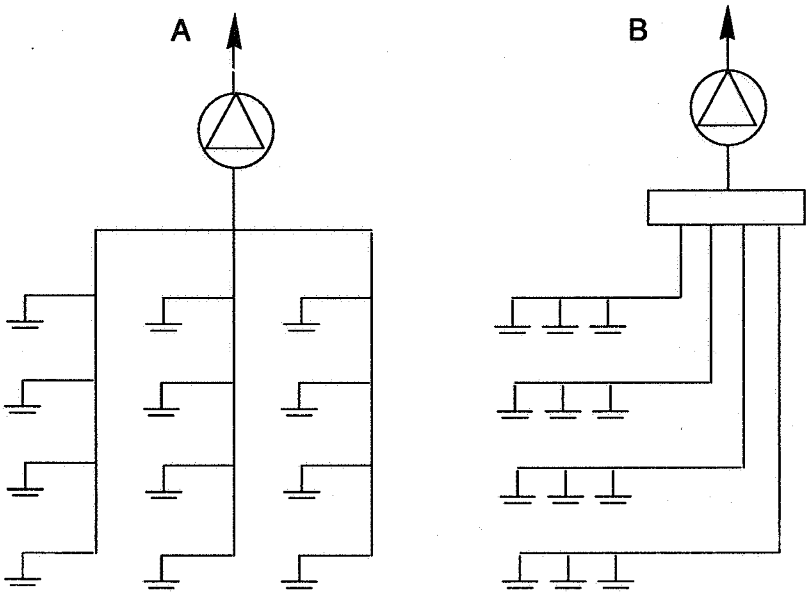


Figure 5. Ducting principles for the dwelling-specific supply sub-building-specific extraction ventilation system.
A Dwelling-specific vertical extract ducts
B Separate vertical ducts in kitchens, bathrooms etc.

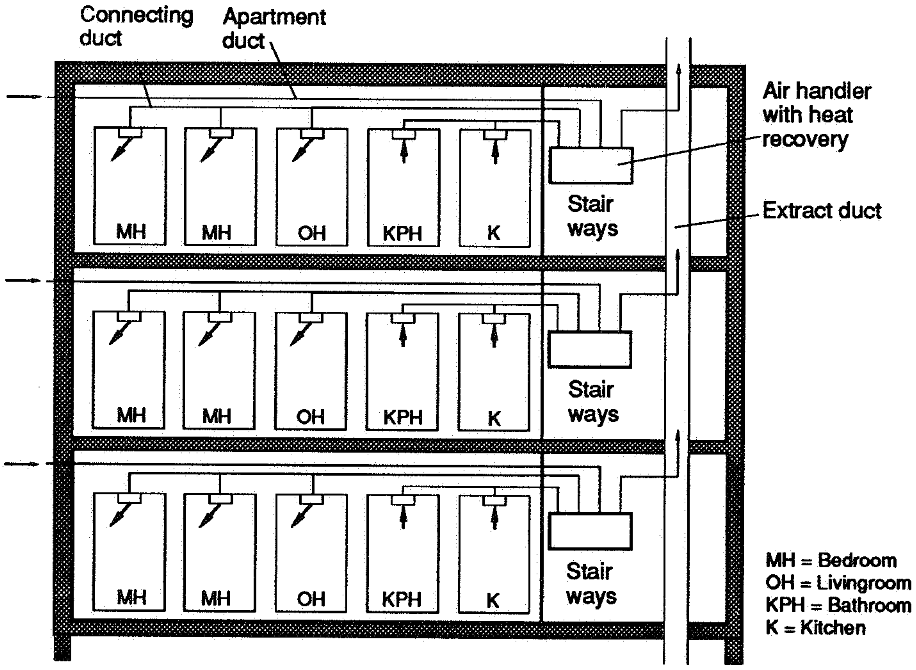


Figure 6. A dwelling-specific supply and extract ventilation system.

Discussion
Paper 4

W.Raatschen (Dornier GmbH, Germany)

a) How do you achieve a low cost DCV system? You said you need bigger duct work, variable fan speed sensors, dampers etc., all things which cost much money. b) You said every occupant should use the ventilation system as he wants. Could you point out what interferences and ways to operate the system a user should have?

R.Kohonen (VTT, Finland)

First I would like to remark that the costs of ventilation systems cannot be considered separately from the other systems. But to answer your question. We made parallel designs for a house of dwellings. We found that the investment costs of HVAC systems with DCV are 30-50% higher than those of our reference system (common vertical duct exhaust system). But if we take into account the operational cost the difference of annual costs are not much different. I am sorry if you got the impression that occupants should use the ventilation system as they want. My remark was that occupants should be able to use ventilation according to their needs. In our paper we give the system descriptions that give us the limitations to the demand-based use

J.Van Der Maas (LESO, EPFL, Switzerland)

Demand controlled ventilation systems require a knowledge of the room temperature behaviour during accelerated ventilation in order to access the comfort level during ventilation. Do you include thermal air stratification in your modelling? Indeed this can have much influence on the comfort.

R.Kohonen (VTT, Finland)

Thermal stratification was not included in our thermal modelling but surface and air temperatures were used to circulate PPD-indices. But in the table giving recommendations for the range of ventilation acceleration we take into account some practical limitations like the maximum fresh air intake airflow per airvent (6 dm3/s) in order to not cause draught or thermal discomfort.