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Guidelines for Performance Based Innovative Mechanical Ventilation Systems

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Synopsis
The development of guidelines for performance based innovative mechanical ventilation systems in residential and commercial buildings is included in the European Commission project TIPVENT "Towards Improved Performances of Mechanical Ventilation Systems". The overall aim of TIPVENT is to promote improved performances of mechanical ventilation systems and the introduction and implementation of innovative designs. The development of performance oriented procedures for designing, commissioning and maintaining mechanical ventilation systems plays a key role in the project. The target group of the guidelines is practitioners. The entire life cycle of a building i.e. from the brief until deconstruction is taken into consideration. The guidelines are summarised and discussed here.

The importance of performance specifications and their verification on-site are emphasised. Special attention is paid to efficient use of electricity, low sound levels, life cycle perspective, use of building energy management system and operation and maintenance. These are areas where the performance of ventilation systems can and should be improved using conventional and innovative technologies. For the life cycle perspective is stressed that life cycle cost analysis should be performed. As to operation and maintenance, operational and maintenance instructions and monitoring are highlighted.

1. INTRODUCTION

Due to an increase in mould growth and condensation problems and later on because of concerns about the indoor air quality in buildings, the use of ventilation systems has become more and more common in many countries. Ventilation of course results in an increased use of energy use for heating and sometimes for warmer climates also for cooling. Consequently ventilation may in e. g. office buildings with high internal loads actually reduce the energy use for cooling. The real performances of mechanical ventilation systems do often not meet the requirements/design specifications (e.g. 1) and do not always fulfil the expectations of the users (e.g. 2).

Therefore a research project supported by the European Commission within the framework of the Joule programme "TIPVENT - Towards Improved Performances of Mechanical VENTilation Systems" (3) was initiated and started in 1998. The aim of TIPVENT is to promote improved performances of mechanical ventilation systems and the introduction and wider use of innovative designs. The development of performance oriented procedures for designing, commissioning and maintaining mechanical ventilation systems plays a central role in the project. There are seven different tasks: impact of ventilation requirements on energy demand, field evaluation of system performances, impact of standards and regulations on the performance, development of a performance oriented approach, development of guidelines for performance based mechanical ventilation systems, development of smart systems and concepts for improved performances – application of developed approach and dissemination. The participating countries are Belgium, France, Great Britain, the Netherlands, Portugal, Sweden and Switzerland. The participants represent research and testing institutes, universities, consulting engineers and manufacturers.

Below the developed guidelines (4) for performance based mechanical ventilation systems are summarised and discussed. The guidelines are based on a TIPVENT study of current design methods for ventilation systems in residential and commercial buildings (5) and on recent research and development findings. The purpose of the guidelines is to give guidance to practitioners (primarily HVAC-designers and building managers, secondly clients and building users) concerning how to bring about ventilation systems with good performances applying conventional and innovative technologies. The guidelines are applicable to residential and commercial buildings, and during the entire life cycle of a building i.e. brief, design, construction, commissioning, operation, maintenance and deconstruction. Seven different chapters are included: performance specifications, design, construction, commissioning, operation and maintenance, deconstruction, life cycle analysis and application on innovative systems.

2. PERFORMANCE SPECIFICATIONS

Applying performance specifications to ventilation systems provide a more flexible and less rigid approach to ventilation system design and operation whereby targets are set which must be met in order that the ventilation system performs as required (6). This approach also facilitates the implementation of innovative systems.

Performance specifications can be applied to a wide range of criteria that influence the overall performance of a ventilation system and at three different levels:

- building (energy use, maintenance cost, IAQ, noise levels)
- system (energy use, maintenance, IAQ, ventilation rate, noise levels, draft, air/operative temperature, thermal comfort, humidity)
- and component.

In practice the performance of ventilation components influence the overall performance of the ventilation system, which in turn influence the overall performance of the building and its occupants. Ventilation systems are significant consumers of energy and therefore it is important that ventilation systems are energy efficient.

Performance specifications must meet certain criteria in order to be successful in implementation: measurable in order to enable verification and checking against set targets, predictable in order to enable design, technically "sound", relevant to the criteria in question, resulting in reasonable life cycle cost, and defensible during possible litigation.

The overall performance specifications should be specified by the client in the brief. The specifications for commissioning, operation, maintenance and deconstruction are preferably made by the designer.

The specifications should also include non-technical aspects such as to what degree the user and occupant can control the system, the level of user friendliness of the system to the occupants, what kind of user instructions are required.

The performance specifications must be verifiable. As a complement to the technical verifications it is often useful to ask the occupants about their perception of the indoor climate, preferably employing a standardised indoor climate questionnaire.

One very important prerequisite for performance specifications for a ventilation system is that the building itself does not emit chemicals at such a level as to constitute a health hazard. All buildings should fulfil this prerequisite. Ventilation should be for the benefit of occupants. Another important prerequisite is that the building envelope is sufficiently airtight. Most of the ventilating outdoor air should enter the building through the ventilation provisions. The same approach should apply to the used air leaving the building i.e. the used air should leave through the ventilation provisions. This in order to be able to control the ventilation.

3. DESIGN

The aim is to design a ventilation system, which fulfils project specific performance specifications, applying conventional and innovative technologies. The design of the ventilation system has to be co-ordinated with the design work of the architect, the structural engineer, the electrical engineer and the designer of the heating system. This in order to ensure that the finished building with heating and ventilation system performs well. Last and not least the building manager or if not possible another experienced building manager should be consulted as to his/her special wishes. He/she will be responsible for the operation of the ventilation system for many years to come.

The designer has to determine certain factors (properties) for the ventilation system, in accordance with the performance specifications:

- Ventilation system: principle, air flow distribution, ventilation efficiency, controllability, use of electricity, use of energy, sound level, operational properties and maintainability, measurability and adjustability, cleaning accessibility, air tightness, quality of building management system.
- Duct system: principle, pressure profile, sound level, air tightness, durability, operational properties and maintainability, protective properties, connection to other systems.
- Fan: type of fan, air flow capacity and pressure set up, electric motor power, sound and vibration level, mechanical stability, efficiency, cleaning accessibility, connection to other systems.

These factors (properties) should be chosen in such a manner that the overall system will have the lowest life cycle cost for the specified level of quality. An economical optimisation should be carried out taking into account:

- Investment costs
- Operating costs (energy)
- Maintenance costs (change of filters, cleaning of ducts, cleaning of air terminal devices etc.)

The following prerequisites are necessary for a performance based design:

- Performance specifications (concerning indoor air quality, thermal comfort, energy efficiency) have been specified for the system to be designed.
- A life cycle perspective is applied.
- The ventilation system is considered as an integral part of the building.

Below, areas are highlighted where performance requirements are likely to be introduced or made more stringent in the near future, as they are either missing or not being considered seriously enough in current design and construction. The performance within these areas can and should be improved.

3.1 Efficient use of electricity

In order to increase the efficiency of the use of electricity the following measures are of interest:

- Optimise the overall layout of the ventilation system e.g. minimise the number of bends, diffusers, cross section changes, T-pieces.
- Change to a fan with higher efficiency (e.g. directly driven instead of belt driven, more efficient motor, backward curved blades instead of forward curved)
- Lower the pressure drop at the connection fan – ductwork (fan inlet and outlet)
- Lower the pressure drop in the duct system e.g. across bends, diffusers, cross section changes, T-pieces.
- Install a more efficient technique of controlling the air flow (variable fan speed employing frequency or fan blade angle control instead of voltage, damper or guide vane control)

Of importance to the overall use of electricity for ventilation is of course also the airtightness of the ductwork, the air flow rates and the operational times.

In order to show the difference between a system with very low pressure drops and a system with up to now current practise an "efficient system", SFP (specific fan power) = 1 kW/m³/s, was compared with a "current system", SFP = between 5.5 – 13 kW/m³/s (see table 1). A very efficient system can have a value of 0.5.

Table 1. Calculated pressure drops and SFP-values for an "efficient system" and a "current system".

	Pressure drop, Pa	
Component	Efficient	Current practise
Supply air side		
Duct system	100	150
Sound attenuator	0	60
Heating coil	40	100
Heat exchanger	100	250
Filter	50	250
Air terminal device	30	50
Air intake	25	70
System effects	0	100
Exhaust air side		
Duct system	100	150
Sound attenuator	0	100
Heat exchanger	100	200
Filter	50	250
Air terminal devices	20	70
System effects	30	100
Sum	645	1950
Assumed total fan efficiency, %	62	15 – 35
Specific fan power, kW/m³/s	1	5.5 – 13

3.2 Low sound levels

Very important in order to ensure low sound levels from ventilation systems are that the pressure drops are low. Low pressure drops can be achieved by the following means:

- Low air velocity i.e. large duct dimensions
- Flow technically correct designed components i.e. minimising changes in duct orientation and size
- Low number of dampers and if dampers have to be used well designed ones
- Good flow conditions at air inlets and outlets

With low pressure drops established a fan running at a low rotational frequency can be chosen.

The following techniques for controlling the air flows are suitable, taking sound into account:

- Control of the rotational frequency of the motor
- Changing the angle of the fan blades of axial fans

If the thus designed ventilation system does not fulfil the sound requirements, then most likely sound attenuators have to be included into the design. Do not forget that noise can enter through the ventilation system e.g. wind noise through outdoor air vents.

3.3 Life cycle cost

The choice of ventilation system is usually strongly influenced by the costs i.e. usually the investment cost and not the life cycle cost. This often means a ventilation system that just fulfils the requirements of the building code at the lowest investment costs. For a major pump it can be shown that 90 % of the life cycle cost is the energy cost for operating the pump, 5 % is maintenance cost and 5 % is the investment cost. The conditions are similar for fans.

A straightforward method used for life cycle cost analysis is to calculate the net present value. The method combines investment, energy, maintenance and environmental cost during part of or the entire operational phase of a building. The yearly cost for energy, maintenance and environment are recalculated to a cost at present, today (7):

$$LCC = Investment_{installation} + Investment_{building} + \sum Energy\ costs_{electricity,\ heat\ etc.} + \sum Maintenance\ costs + \sum Environmental\ impact\ costs - Remaining\ value$$

With this method different systems can be compared. The environmental impact in costs is usually very difficult to determine and is therefore often left out. The environmental impact is to some extent taken into account by including energy. Often the LCC calculations are made to optimise the energy costs during the period of operation. The main part of the life cycle energy use of a building is during this period i.e. space heating, ventilation, hot water production, electricity and lighting. Assuming the life span of a building to be 50 years, the operating period accounts for 80 – 85 % of the total energy use (8).

3.4 Use of building management system

The building management system (BMS) of a building and the routines for following up measurements and alarms, determine the possibilities to obtain a proper operation of the heating and ventilating system. An optimum operation of the heating and ventilating system demands that the sub-processes can be monitored separately. This is also often the only approach to discover small discrepancies in a system which by themselves do not increase the energy use enough to activate an energy use alarm (by maximum levels or follow up procedures). One example is problems with a fan motor, which does not show on the total electric energy use for the operation of a building.

This does not mean that every ventilation system should be monitored by a BMS. For all but the smallest and simplest systems BMS should be considered. For a very complex and large ventilation system a BMS is probably necessary.

The level of sophistication of a BMS has to agree with the knowledge level of the operational staff. The best approach is to compile detailed performance specifications for the BMS.

3.5 Operation and maintenance

In order to enable proper operation and maintenance appropriate operation and maintenance instructions have to be written. For these instructions to be useful certain criteria have to be fulfilled during the design of the ventilation system:

- The technical systems and their components must be accessible for maintenance, exchange etc.. Fan rooms must be sufficiently big and equipped with good lighting. The individual components (fans, dampers etc.) of the ventilation system must be easily accessible.
- The systems must be marked with information as to medium in pipes and ducts, direction of flow etc.
- If the operation and maintenance instructions are prepared during the design phase, it will be easier and cheaper to finalise them.

4. OPERATION AND MAINTENANCE

Often the maintenance of ventilation systems is inadequate, resulting in poor performance. To ensure good indoor air quality and energy efficiency the ventilation systems must be operated in an efficient way. Prerequisite for proper operation and maintenance of a ventilation system are good controllability (enabling good control), maintainability (enabling proper maintenance), adjustability (enabling adjusting), cleanability (enabling cleaning) and operational and maintenance instructions.

Very few of today's systems are provided with appropriate instructions. The instructions have to:

- Give overall knowledge concerning the design, the function and safety aspects
- Describe operating modes
- Describe the operation and maintenance work

The instruction must be made with regard to:

- Type of building or process
- Type of user the building or process is intended for
- The level of knowledge of the operations and maintenance crew

The routines for operational monitoring of a ventilation system are crucial for the possibilities to obtain a proper operation. Proper operation requires monitoring not only of the main systems, but also the sub-systems.

Very important for ventilation is the reliability of the ventilation system i.e. the probability that a ventilation system performs in acceptable way for a given building in a given climate between scheduled maintenance.

Ventilation systems, especially mechanical ones, are subject to ageing of its components, fouling, user manipulations etc. The risk for breakdown of components such as fan motors, bearings, fan belts etc. increases with the time the system is used. This is normally referred to as life times. Fouling of ducts is critical to the reliability of ventilation systems. It is obvious that the maintenance intensity and the quality of the components are very important to the reliability of the ventilation system.

5. LIFE CYCLE ANALYSIS

Buildings must be made sustainable i.e. a building must during its life time have a as small as possible impact on the environment. Responsible for this are several different categories of persons e.g. designers, building managers. Products are to be judged from a life cycle perspective, where attention must be paid to all impacts on the environment during the entire life cycle. At an early stage the designer, the buyer and the contractor can make environmentally friendly choices. A building will change during its life span and besides it consists of several different components with different life spans. Usually the components of the ventilation system have a shorter life span than most other parts of the building e.g. the structural parts.

A literature study of building service components and systems from a life cycle perspective (9) shows that so far not much work has been undertaken from this perspective concerning ventilation systems. The choice of ventilation system is usually strongly influenced by the costs i.e. usually the investment costs and not the life cycle costs. This often means a ventilation system that just fulfils the requirements of the building code at the lowest investment costs. Important factors relevant to life cycle perspectives are:

- Life span.
- Environmental impact.
- Ventilation system changes.
- Cost analysis.

When determining the life span one has to take into account the technical, the economic and practical life span. The technical and economic life span of a ventilation system is usually shorter than the life span of the building itself. The range of the technical and economic life span is shown in table 2.

Table 2. Technical and economic life spans, assuming maintenance has taken place, from different references (7).

Component	Years
Ventilation ducts	25 – 50
Fans	25 – 30
Air terminal devices	25 – 50
Electrical cables	30 – 60
Electrical switches and outlets	30 - 50

Very often the practical life span of a ventilation system is determined by the time span a building will be used for the current purpose. During design maintainability and flexibility of the ventilation system have to be taken into account i.e. that the use of e.g. an office building can change several times during the life span of the building. The reasons for renovation or reconstruction are more often changed needs caused by changed use than too much wear and tear or that the installations have become old fashioned, that spare parts for expiring products only are kept in store for a limited period of time or for other reasons do not fulfil the demands of today. This is often the case for commercial buildings.

A straightforward method of calculating the life cycle cost is to calculate the net present value (see chapter 3.3). LCC calculations can be a very useful tool for a retrofit of a ventilation system as well as for a new ventilation system comparing different alternatives. New tools and software are being developed.

5. CONCLUSIONS

There are many ways of encouraging the implementation of well performing conventional and innovative ventilation systems: regulations, additional financial support, education/information and market forces. In order to facilitate the implementation a performance oriented approach to ventilation has to be developed. To begin with, the regulations and standards have to require quality by better specifying the performance of ventilation systems than is currently the practice. The clients and users have to ask for quality by specifying requirements corresponding to a desired performance. A performance oriented procedure for ventilation should apply to not only the design but also to the construction, commissioning, operation, maintenance and deconstruction. All the different phases of the life time of a ventilation system have a strong influence on how the system will perform in operation. A performance oriented approach to mechanical ventilation systems provides a more flexible approach to ventilation system design and operation, thereby facilitating the implementation of innovative systems.

The purpose of the guidelines is to give guidance to practitioners as to how to bring about ventilation systems with good performances applying conventional and innovative technologies. First of all the brief has to specify the desired quality (performance specifications), then the designer has to design a ventilation system fulfilling the quality requirements. The contractor must build a system meeting these requirements. It must be possible to verify the performance on-site. Finally the operation and maintenance crew have to ensure that the performance according to the desired quality level is maintained during the life time.

Examples of areas where the performance of ventilation systems can and should be improved are use of electricity, sound levels, life cycle perspective, operation and maintenance. As to life cycle perspective it is very important to carry out life cycle cost analysis. During operation and maintenance, good operational and maintenance instructions and appropriate monitoring are crucial.

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