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FOR A SUSTAINABLE FUTURE

Educational Package Ventilation

Lecture 10: Commissioning, control and measures in ventilation

IEE/09/631/SI2.558225
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Summary

- Testing of Ventilation System
- Measurement of Volumetric Flow Rate
- Air Velocity Measuring Instruments
- Calibration of Air Measuring Instruments
- Difficulties Encountered in Field Measurement
- Design principles of a clean ventilation system
- Acceptability of filtered air

Testing of Ventilation System

Purpose:
- To verify the volumetric flow rate(s)
- To check the performance of the system periodically
- To obtain specific information and compare with design data
- To set baseline for periodic maintenance checks
- Basis for design of future installations where satisfactory air contaminant control is currently being achieved
- To meet governmental or regulatory requirements for certain types of processes

Types:
- Initial testing
- Periodic testing

Source : www.eng.utoledo.edu

Recommended Procedure for Initial Ventilation Test

1) **review the system specifications and drawing to determine the relative location and sizes of ducts, fittings and associated system components;**

2) **inspect the system to determine that the system installation is in accordance with the specifications and drawings. (Check fan rotation, belt slippage, and damper settings);**

3) **select and identify test locations;**

4) **measure the volumetric flow rate, fan static pressure, fan speed, motor speed, motor amperes, the temperature of the air in the system, pressure drops across coils, fittings and air cleaning equipment's.**

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Recommended Procedure for Initial Ventilation Test

5) record the test data and design specifications on the data sheet.

6) compare the test data and design specifications.

7) make necessary amendments to meet the specifications, codes or standards.

8) if alterations or adjustments are made, retest the system and record the final test data.

- Source : www.eng.utoledo.edu

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Recommend Procedure for Periodic Testing:

1) refer to the initial data sheet for test locations.
2) inspect the system for physical damage (broken, corroded, collapsed duct) and proper operation of components (fan, damper, air cleaner, controls, burner etc.).
3) measure static pressure at the same locations used in the initial test.
4) compare measured static pressures with initial test.
5) make and record any correction required.
6) recheck the system to verify performance.

- Source : www.eng.utoledo.edu

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Measurement of Volumetric Flow Rate:

Volumetric Flow Rate:
Q = V * A
Where:
V = average air velocity and
A = average cross-sectional area
Important parameter to measure is Average air velocity
Pressure Measurement:
At any point in the exhaust system, three air pressures exist
TP = SP + VP
Where:
TP = Total Pressure in "wg
SP = Static Pressure in "wg
VP = Velocity Pressure in "wg

Source : www.eng.utoledo.edu

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Pressure Measurement

Static Pressure:

- **Pressure which tends to burst or collapse a duct**
- **Positive when > atmospheric**
- **Negative when < atmospheric**

Instruments Used for Measurements:

- **Simple Piezometer**
- **Simple U-tube Manometer filled with oil or appropriate liquid**
- **Water gauge**
- **Reading pressure gauge**
- **Inclined manometer gives increased accuracy and permits reading of lower values of velocities**

Source : www.eng.utoledo.edu

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Instruments Used for Pressure Measurements

U-Tube Manometer:
- Simplest type of pressure gauge.
- Calibrated in inches of water gauge.
- Fluid used are alcohol, mercury, oil, water, kerosene and special manometer fluids.
- Can be used for both portable and stationary applications.
- Usually made of plastic, to minimize breakage.

Inclined Manometer:
- One leg of the U-tube is tilted for scale magnification.
- Increased sensitivity.
- In commercial version, only one tube of small bore is used and other leg is replaced by a reservoir.
- Accuracy of the gauge is dependent on the slope of the tubes.

Source : www.eng.utoledo.edu

Instruments Used for Pressure Measurements

Aneroid Gauges:
- Used as field instrument to measure static, velocity, or total pressure with a Pitot tube or for single tube static pressure measurements.
- Suitable for the measurements of low pressures.
- Easy to read, portable, and greater response than manometer types.
- Absence of fluid means less maintenance.
- Mounting and use in any position is possible without loss of accuracy.

Source : www.eng.utoledo.edu

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Instruments Used for Pressure Measurements

Electronic Aneroid Gauges:

- Measures and records static pressure as well as integrate velocity pressure directly to velocity.
- Uses the principle of pressure sensing.
- Can be equipped with digital display or print recorder with measurement data in either English or S.I units.

- Source : www.eng.utoledo.edu

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Hood Static Pressure

Hood Static Pressure:

- Method of estimating air flow into an exhaust hood or duct is based on the principle of the orifice.
- Method is quick, simple and practical.

Procedure of Measurement:

- This technique involves the measuring of hood static pressure by means of a U-tube manometer at one or more holes.
- The manometer is connected to each hole in turn by means of a thick walled soft rubber tube.
- The difference in height of the water columns is read in inches.
- After hood static pressure (SP_h) is known, the volumetric flow rate is determined as.

- Source : www.eng.utoledo.edu

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Equation for Flow Rate

$Q = 4005 * A * C_e * \sqrt{SP_h}$.

Where:

Q = flow rate in fpm.

A = Average cross-sectional area in sqft.

C_e = Coefficient of entry loss.

SP_h = Static pressure in the hood or the duct.

Points to Remember while Measuring Pressure:

- **Avoid pressure measurement at the heel of an elbow or other location.**
- **Drill 2-4 pressure holes at uniform distances around the duct and obtain the average.**
- **Hole should be drilled not punched.**
- **When in use, the instrument must be pointed upstream and parallel to the duct for accurate measurement.**

Source : www.eng.utoledo.edu

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Velocity Pressure

- **To measure velocity pressure and velocity of flow Pitot tube is used.**
- **The device consist of two concentric tubes.**
- **One measures the total or impact pressure existing in the air stream.**
- **Other measures the static pressure only.**
- **The annular space and center tube are connected across a manometer. The velocity pressure is indicated on the manometer.**
- **The velocity of air stream for standard conditions is determined as.**

Source : www.eng.utoledo.edu

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For other then standard conditions, equivalent velocity pressure

$VP_e = VP_m$ /df

Where

VP_e = equivalent velocity pressure in "wg

VP_m = measured velocity pressure "wg

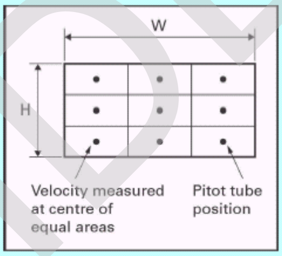
df = density correction factor

Pitot Traverse Method:

- **Method to select points along the duct cross-section to measure the velocity pressure**
- **Usual method is to make two traverses across the diameter of the duct at right angles to each other**
- **Readings are taken at the center of annular rings of equal area as shown in the figure**

Source : www.eng.utoledo.edu

Diameter range (mm) and application	Number of diameters traversed	Distance of pitot tube from duct walls, fraction of diameter						
		1	2	3	4	5	6	



Number of readings	Distance of each reading from duct wall (fraction of total)				
	1	2	3	4	5
2	0·25	0·75			
3	0·17	0·50	0·83		
4	0·13	0·38	0·63	0·88	
5	0·10	0·30	0·50	0·70	0·90

Height mm	Width (mm) and number of readings							
	Up to 200		200-500		500-900		Over 900	
	Down	Across	Down	Across	Down	Across	Down	Across
Up to 200	2	2	2	3	2	4	2	5
200-500	3	2	3	3	3	4	3	5
500-900	4	2	4	3	4	4	4	5
Over 900	5	2	5	3	5	4	5	5

- * Multiply this single-point reading by 0·8 to obtain average velocity

Important Points to Consider

- The velocity pressure reading obtained are converted to velocities and the velocities, not the velocity pressure, are averaged.
- The square root of each of the velocity pressure may be averaged and this value then converted to velocity (average).
- Pitot tube is not suitable for measuring velocities less than 600 fpm.

Source : www.eng.utoledo.edu

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Air Velocity Measuring Instruments

1) Rotating vane anemometer
2) Swinging vane anemometer
3) Thermal anemometer
4) Smoke tubes
5) Tracer gas method
6) Pitot tubes

Source : www.eng.utoledo.edu

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Rotating Vane Anemometer

- Used to determine air flow through large supply and exhaust openings.
- Cross-sectional area of the instrument not greater than 5.0% of the cross-sectional area of the duct or hood opening.
- Used for either pressure or suction measurements.
- Is useful for a range of 200 - 300 fpm.
- Readings as low as 25 fpm can be measured and recorded using electronic type.

Source : www.eng.utoledo.edu

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Swinging Vane/Thermal Anemometer

Swinging Vane Anemometer:

- Used for field measurements.
- Highly portable, has wide scale range and gives instantaneous readings.
- Minimum velocity measured is 50 fpm, unless specially adapted for lower range.

Thermal Anemometer.

Principle: Amount of heat removed by an air stream passing a heated object is related to the velocity of the air stream.

Components: Velocity sensor & Temperature sensor.

Source : www.eng.utoledo.edu

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Tracer Gas Method

- Tracer gas is metered continuously into one or more intake ports along with entering air stream.
- Air samples are collected at some point downstream.
- The concentration of tracer gas in the exit stream is determined.
- The rate of air flow equals the rate of feed divided by tracer gas concentration.

Source : www.eng.utoledo.edu

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Calibration of Air Measuring Instruments

Need: Easily impaired by shock (dropping, jarring), dust, high temperature and corrosive atmosphere.

Calibrating Wind Tunnel Components:

1) A Satisfactory test section:

- Section where the sensing probe or instrument is placed.

2) A Satisfactory means for precisely metering the airflow:

- The meter on this scale must be accurate and with large enough scale graduation (precision + 1%).

3) A means of regulating and effecting air flow through the tunnel:

- The regulating device must be easily and precisely set to the desired velocities.
- Fan must have sufficient capacity to develop maximum velocity.

Source : www.eng.utoledo.edu

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Corrections for Non Standard Conditions

Density of air depends on elevation, pressure, temperature and moisture content

The actual air density of the system should be used to determine the actual velocity

Actual air density = 0.075 df

dfe = CFeCFpCFt

Where:

CFe = correction for elevations outside the range of + 1000 ft

CFp = correction for local duct pressures greater than + 20 " wg

CFt = correction for temperatures outside the range of 40 to 100

Correction Coefficient for Elevation:

CFe = [1 - (6.73 x 10 -6)(z)]5.258

Where:

z = elevation, ft

Source : www.eng.utoledo.edu

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Corrections for Non Standard Conditions

Correction Coefficient for Local Duct Pressure:

CF_p = (407 + SP)/407

Where

SP = static pressure, " wg

(Note that the algebraic sign of SP is important)

Correction Coefficient for Temperature:

CF_t = 530/ (t + 460)

Where

t = dry-bulb temperature, F

(Note algebraic sign of t must be used)

Source : www.eng.utoledo.edu

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Difficulties Encountered in Field Measurement

- Measurement of air flow in highly contaminated air which may contain corrosive gases, dusts, fumes, mists, or products of combustion.
- Measurement of air flow at high temperature.
- Measurement of air flow in high concentrations of water vapor and mist.
- Measurement of air flow where the velocity is very low.
- Measurements of air flow in locations of turbulence and non-uniform air flow.
- Measurement of air flow in connection with iso-kinetic sampling when the velocity is constantly changing.

Source : www.eng.utoledo.edu

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Sensors

Figure 10: A collection of typical sensors and low voltage controls for a ventilation system.

Courtesy of NuAire.

Fig. 1

Source : Wind-Driven Natural Ventilation Systems, a BSRIA Guide, James Parker and Arnold Teekaram, 2005

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Sensors

Figure 11: A typical temperature-based ventilation scheme.

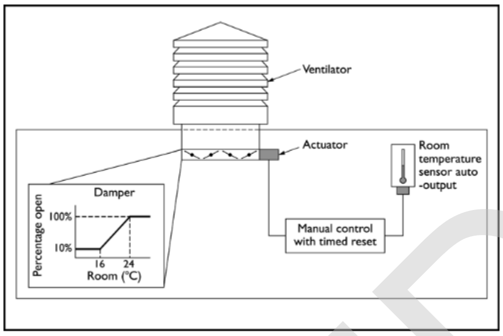

Fig. 2

Source : Wind-Driven Natural Ventilation Systems, a BSRIA Guide, James Parker and Arnold Teekaram, 2005

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Blower door test

Diagnostic Tools

Testing the airtightness of a home using a special fan called a blower door can help to ensure that air sealing work is effective. Often, energy efficiency incentive programs, such as the DOE/ EPA ENERGY STAR Program, require a blower door test (usually performed in less than an hour) to confirm the tightness of the house.

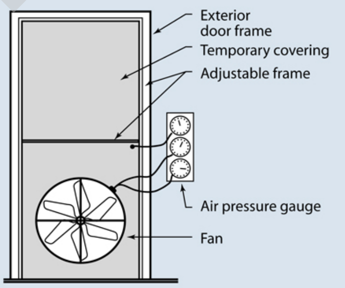

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Fig. 3 a,b

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Cleanliness criteria for ventilation systems

- Different need for criteria for dust deposits in the system
  - existing systems (maintenance)
  - new systems (commissioning)
- The major contaminants to avoid (in New system)
  - dust deposits, amount of oil residues, filings from installations
- Criteria for various components (in the existing systems)
  - filters
  - coils
  - humidifiers
  - cooling tower

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Design principles of a clean ventilation system

- The goal of design is to design high IAQ, the other things are involved in it
- Design
  - Setting the IAQ target values in conceptual design process with user, architect and mechanical engineer
  - Design phase mechanical designer designs the clean HVAC system according to specifications and gives the instruction of the methods in aiming to clean HVAC system

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Design principles of a clean ventilation system

The goal of design is to design high IAQ!

- **Critical design features:**
  - placing of fresh air intake, and exhaust, mechanical room, selection of components
  - dimensioning; air velocities in air grilles and louvres, cooling coils, heat exchanges, high efficiency filtration (2 steps),
  - sound attenuators, selection of materials (low fibre release)
- **Installation with "low dust" clean technique, protection of open ends**
- **Contract document**
- **Good documentation and instructions for maintenance of cleanliness guarantees the continuity of the information transfer**

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The Problem:

Many air-conditioning systems are planned, manufactured, executed and operated in a badly hygienic way

Fig. 4 a,b,c,d,e

Design principles of a clean ventilation system

- Design and maintenance aspects
  - cleanability
    - openings
    - sufficient space
    - dimensions
- More details in the referred main documents
  - EN 12097, EN 13053, EN 13779
  - FiSIAQ 2001, D2, VDI 6022

Fig. 5

Installing a clean ventilation system

- protecting against impurities
  - continually during all the building processes
    - storage

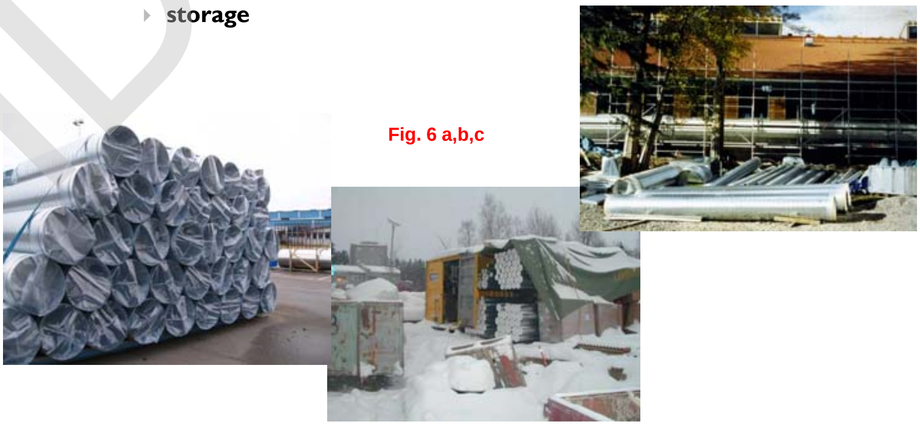


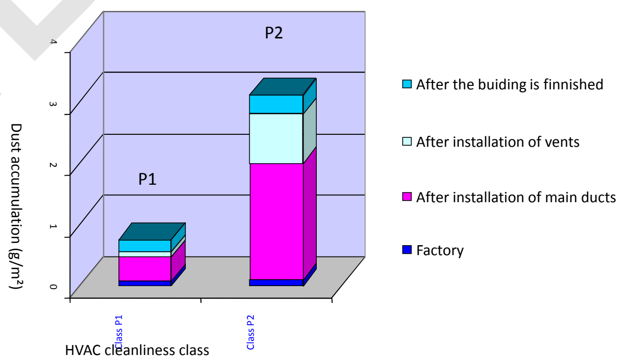
Fig. 6 a,b,c

Installing a clean ventilation system

- levels of cleanliness
  - basic
    - demands for manufactured products
    - delivery; not specially protected
    - checking of the cleanliness before installation; debris free
    - not special requirements for covering
  - intermediate
    - storage area should be clean and dry
    - component should be covered during installation
  - advanced
    - ducts and components should be capped or protected in all phases of construction, including transportation and storage

Installing a clean ventilation system

- Dust accumulation on duct in different building processes
  - Efforts of cleaning control in ventilation systems built according cleanliness control protocol (P1) and less demanded control (P2)



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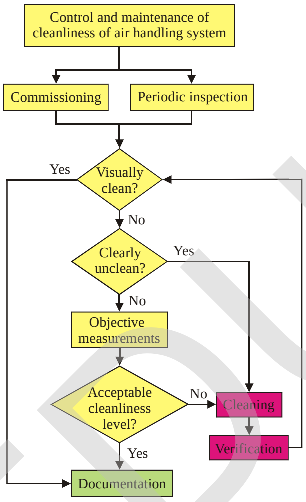
Verification of the cleanliness of ventilation system

- **Evaluation methods**
  - **visual inspection**
    - **aided with visual scale**
    - **recommended as a basic method**



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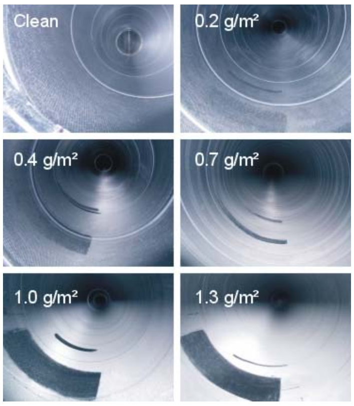
Installing a clean ventilation system

- **protecting against impurities**
    - **installation work (cutting the ducts, closing the open endings)**
    - **timing the working processes:**
      - **do balancing and flow measurements when no dust sources are present in the building site**
      - **do no clean the ductwork or system before all construction work is completed**

A set of pictures in newly installed and existing air ducts

Scale for new

Scale for existing



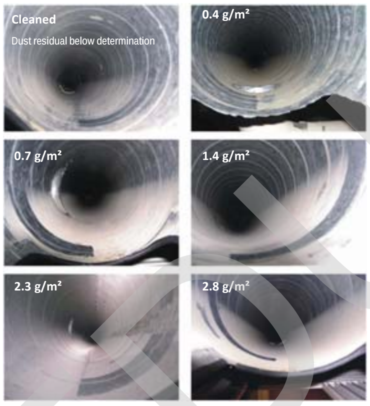


Fig. 7 a,b

Verification of the cleanliness of ventilation system

HOW to quantify the dust deposits

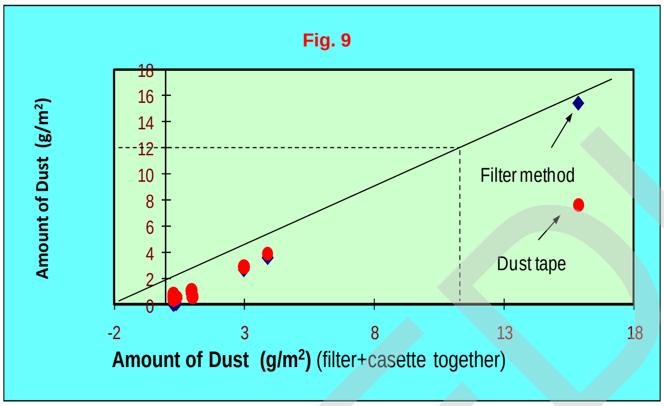
- methods for solid deposits
  - mass
    - sampling on filter with vacuum pump
    - wiping with cloth (with solvent)
    - wiping with cloth (without solvent)
    - tape method
    - vacuum test (NADGA)
  - thickness
  - comp
  - thickness meter

Fig. 8 a,b,c

Verification of the cleanliness of ventilation system

Note the differences in the methods

- **filter sampling (loosening technique)**
- **tape method (capasity of the tape, hygroscopicity)**



Verification of the cleanliness of ventilation system

WHAT else to measure than dust deposit

- microbial contaminants
  - surfaces
  - water systems
- airborne particles
  - mass and number
- fibres
  - on the surfaces, in the air
- oil residues
  - surface (mainly for uninstalled components)

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Cleaning a ventilation system

- Cleaning methods
  - dry cleaning methods
    - mechanical brushing
    - compressed air
    - hand vacuuming
  - wet cleaning methods
    - hand washing
    - steam washing
    - mechanical power washing
      - use of detergents

Fig. 10 a,b

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Cleaning a ventilation system

- Instructions for selection of cleaning methods
  - air intake unit
  - filter chambers and fan
  - heat exchangers and coils
  - humidifiers
  - porous components
    - sound attenuators
    - surfaces of thermal insulations
  - terminal devices
- Disinfection (when and how?)
  - ductwork
    - usually needed only when excessive microbial contamination has been cleaned
  - humidifiers
    - included in a maintenance protocol

Fig. 11

Report and documentation

- Inspection and cleaning work shall be well documented
  - recommendations for detailed information of the contents of the document
    - descriptions of system
    - descriptions of methods use
    - visual information, proofs (photos)
    - conclusions
    - recommendations for building owner and management personnel

Filter as a Biotope

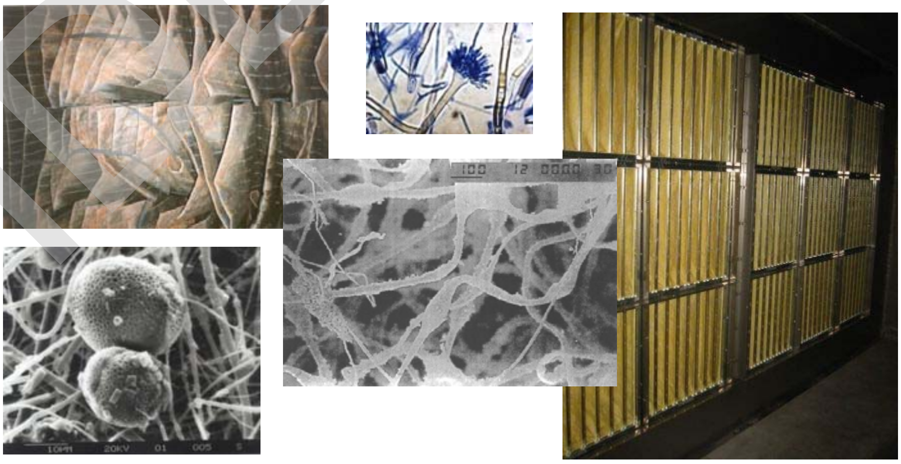


Fig. 12 a,b,c,d,e

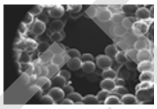
G-FILTER

F-FILTER

Fig. 13

WHY AIR FILTRATION
Work Shop Clima 2010
Antalya, 10-05-09
Jan Gustavsson, JG filter Technology

HEPA, ULPA



Chemical FILTER

Filtration - costs

Air flow	1 m^3/s =1000 L/s
Operation time	6000 hours
Air Filters	F7 + F7
Average pressure drop	120Pa + 100Pa
Filter Replacement	2 times/year
Filter cost	30 €/filter
Fan Efficiency	0.5
Energy price	0.1 €/ kWh
Air flow/person	20 L/s
People served by 1 m^3/s	50
Energy (Q Pa T/η_{fan}/1000)	2640 kWh/year
Energy cost	264 €/year
Filter cost	120 €/year
Total cost	384 €/year
Cost / person	8 €/year
	0,15 €/week
	0,03 €/day

What are we talking about?

A piece of cake?
But important

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Why air filters – Clean industry ?

Fig. 14 a,b

Goal = Output
Good relationship between cleanliness and quality.

Money talks

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Why air filters - Offices?

Goal = lower costs?

Few studies

Improved air filtration (First and Rosenfeld 1997)

Financial benefits from improved indoor environment exceed the filtration cost by a factor of 20

Reduction of exposure to particles (Bekö et al 2007)

- Considering pollutants, morbidity, mortality, productivity, working period, cleaning, energy and filtration cost etc.
- Considering different stakeholders; employers, building owner and society

Regardless of perspective, particle filtration is anticipated to lead to annual savings significantly exceeding the running costs for filtration

Why Air filters - Offices?

However

Economic losses resulting from even a small decrease in productivity caused by sensory pollutants emitted from soiled air filters have the potential to substantially exceed the annual economic benefits of filtration

Why Air filters - Ventilation system

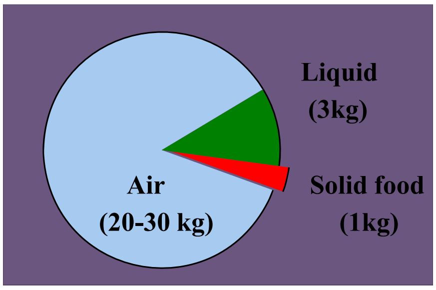
Old problem
"With no cleaning the ventilation will be short-lived"

Fig. 15

- **Keep the system clean**
  - keep the designed Air Flow
    - influence Temperature, RH
    - reduce indoor contaminants from humans, building materials, equipment
  - keep the efficiency of equipment
    - fan, heating, cooling etc.
- **Keep indoor surfaces clean**
- **Avoid Microorganisms in the system**
- **Remove Outdoor contaminants**

Why Air filters - Hygiene (IAQ)

Intake of Air and Food - 24 hours



Indoors
80% -90% of time

What are the requirements for Air?

WHO - IAQ

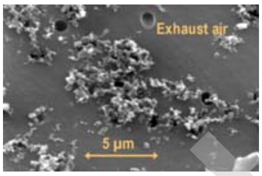
Healthy indoor air is a human right and all groups, individuals or organizations associated with a building have a responsibility to work to achieve an acceptable air quality

- Principle 1. *The human right to health*
  - everyone has the right to breathe healthy indoor air
  - influence on quality of life (not only health)
- Principle 2. *Respect for autonomy (self-determination)*
  everyone has the right to expect others to respect their individual judgement in their own evaluation of personal exposure and its effect.
- Principle 3. "*do no harm*"
  ignorance about indoor air quality is no excuse
- Principle 4. "*doing good*"
  …responsibility to promote good IAQ
- -
- Principle 9….

We have a responsibility

We know

- Outdoor pollutants (types , levels and sizes) in most big cities
- Exposure to urban air pollution is associated with a broad range of acute and chronic health effects
- 50% of Outdoor airborne pollutants are carried into buildings and have a large impact on Indoor Air Quality



- The most widespread indoor cause and source for these health impacts is outdoor air
- Productivity influenced by pollutants
- Comfort influenced by pollutants
- No technical problem to take most of the pollutants in air filters

We know - example

Fine particles - underestimated health risk

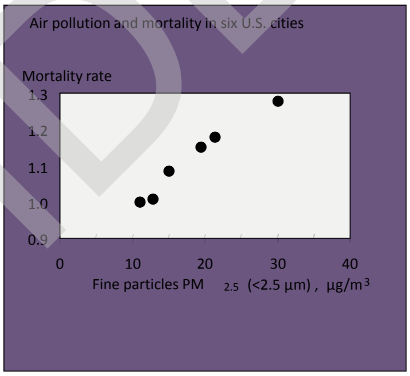


Fig. 16

Ultra-, Nano- or Fine- particles

- Clear connection between fine particles and health effects as mortality and respiratory problems
- Effect on the development of children's lung capacity
- Underestimated risk (long term)
- WHO - no harmless concentration limit
- Official requirements under review
  - Europe and U.S.
  - PM_{10} to $PM_{2.5}$

Air Filters – IAQ problems

An Air filter is one component in a ventilation system and cannot contribute to better IAQ by itself, but is a prerequisite for the system and other components to work properly but it can also be a source of IAQ problem

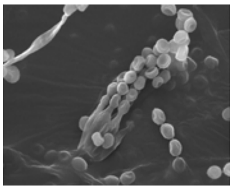


Fig. 17 a,b

- Manufacturing
- Release of particles/gases/microorganisms in operation
- Decrease in efficiency
- Smell from removed pollutants
- Microbial in filters
  - Survive and release VOC(Ketones, alcohols...)
  - Die and release endotoxins, gases/particles
  - Grow and give off microorganisms, spores
- Replacing filters
- Dumping/Disposal
- Global environment (LCA)

Perceived air

Several studies have shown filters to have a negative effect on perception of indoor air quality as

- Influence from new filters is negligible after some days ”off-gassing”
- Soiled air filters
  - Negative effect of perceived indoor air quality
    Filter 0.05 olf/m^2 floor area
    Low pollution office 0.10
    People 0.07
  - Increase sick building syndromes
  - Decrease productivity
  - Release microorganisms, endotoxins etc..

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Standards - Recommendations

- **Maximum permissible concentrations of pollutants are set by national regulations and WHO but no standard values, relevant to health protection or limit values based on technical parameters are available for Indoor Air Quality.**
- **Comfort criteria are sometimes specified and are normally related to air flow rates, CO_2 concentrations or indirectly by discomfort**
- **VDI 6022, EN 13779 and REHVA (No 9) define requirements on air filters and systems to achieve good IAQ and avoid hygienic problems based on some studies and practical experiences**

No specific criteria for pollutants in IAQ design

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AIR FILTERS vs. IAQ

There are some recommendations based on experiences and a few studies

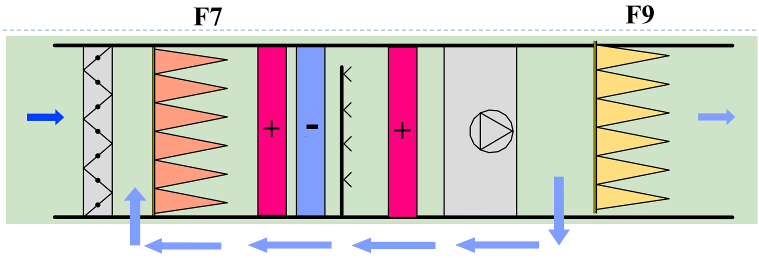
Filter Class vs. Indoor Air Class EN13779

Outdoor Air Quality	Indoor Air Quality IDA 1 (high)	IDA 2 (medium)	IDA 3 (moderate)	IDA 4 (Low)
ODA 1 (pure air)	F9	F8	F7	F5
ODA 2 (dust)	F7+F9	F6+F8	F5+F7	F5+F6
ODA 3 (very high concentrations of dust or gases)	F7+GF*)+F9	F7+GF*)+F9	F5+F7	F5+F6

*) GF Gas filter

60

Hygienic aspects - Design



Humidity
Max. 90 % RH (peaks)
Max. 80 % RH (avg. 3 days)

Two step filtration is recommended
Min. F5 or if possible F7 in the 1st stage
Min. F7 or if possible F9 in the 2nd stage
Min. F7 if only one filter step is used

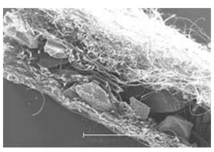
For hygienic reasons the filters should be replaced frequently

- The first filter step should be replaced after 2000 hours operation
- The second filter (or the filter in the recycled system) after 4000 h
- The efficiency may not decrease during operation.

Acceptability of filtered air

- Chemical reactions with filtrated dust reacts with reactive outdoor air gases such as ozone and oxidation products can be formed, which could explain some of the negative effect of perceived air.
- Activated carbon is effective against O_3
- Some new studies indicate that a combination of particle filters and activated carbon will remove a significant fraction of ozone and improve the acceptability of the filtered air.
- These filters could replace commonly existing filters and would have particle removal efficiencies comparable to standard filters. They will improve the indoor air quality with little or no modifications to the air handling system.

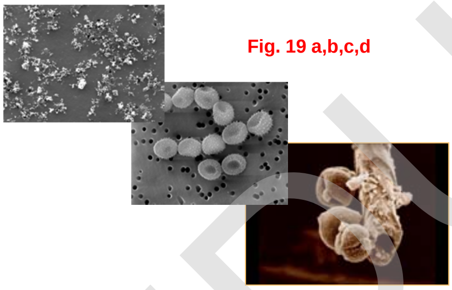
Fig. 18 a,b



Air filters- possibilities

- Protect Ventilation system
  - Keep the function of the system
  - Stop contaminants from entering the system
- Hygienic reasons
  - Particles
  - Micro-organisms
  - Allergens
  - Carcinogens
  - Gases, ozone
- Productivity, comfort

Fig. 19 a,b,c,d



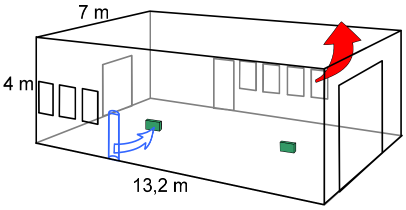
But; Carefully design and operation is a must

Air Filtration today – tomorrow

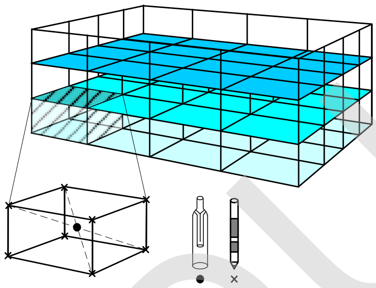
- Today - Use existing knowledge – Air Filtration Guidebook
  - Efficiency
  - Operation time and conditions
  - Filter and energy design (LCC/LCA)
  - Replacement and disposal
- Tomorrow
  - Guidelines for Indoor Environment based on pollutants.
  - Comfort criteria and air filters
  - Requirements based on real filter efficiencies. Not on classifications as F7, F8. The meaning of classes will change
  - Air filters in real life
  - Criteria for LCC and LCA calculations
  - Benchmarking of existing installations

CASE STUDIES

Homogeneous emission techniques



Laboratory hall



Subdivision of the room

Fig. 20 a,b

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CASE STUDIES

Homogeneous emission techniques

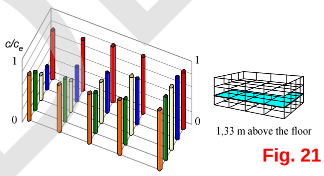
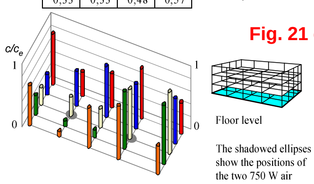


Fig. 21 a,b

0,35	0,42	0,50	0,54
0,28	0,35	0,45	0,60
0,27	0,28	0,43	0,63
0,33	0,33	0,48	0,57

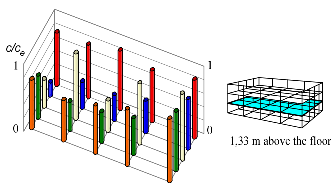
Computed local mean age of air in the sub-volumes between the two layers

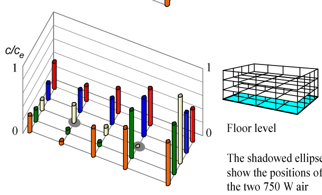
Fig. 21 c,d



The shadowed ellipses show the positions of the two 750 W air convectors at the floor level

Local mean age of air





The shadowed ellipses show the positions of the two 750 W air convectors at the floor level

Local concentrations with point sources

References

- Source : Wind-Driven Natural Ventilation Systems, a BSRIA Guide, James Parker and Arnold Teekaram, 2005
- WWW.eng.utoledo.edu

Levels for the Figures

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Level 3, poor quality: replace the illustration with a link or a reference to where to find the illustration.

Figure Number	Level (1- 3)
Fig 1	3
Fig 2	3
Fig 3 a,b	3
Fig.4 a,b,c,d,e	3
Fig.5	3
Fig.6 a,b,c	3
Fig.7 a,b	3
Fig.8 a,b,c	3
Fig.9	3
Fig.10 a,b	3

Figure Number	Level (1- 3)
Fig 11	3
Fig 12 a,b,c,d,e	3
Fig 13	3
Fig.14 a,b	3
Fig.15	3
Fig. 16	2
Fig.17 a,b	3
Fig.18 a,b	3
Fig.19 a,b,c,d	3
Fig.20 a,b	3
Fig.21 a,b,c,d	3