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PERFORMANCE CRITERIA OF BUILDINGS FOR HEALTH AND COMFORT

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FOREWORD

One of the main purposes of buildings is to provide healthy and comfortable environments for human activities. A building must accommodate the activities it is built for and provide floorspace, room volume, shelter, light and amenities for working, living, learning, curing, processing etc. Furthermore, the building must supply a healthy and comfortable indoor climate to the people using it. In meeting these basic requirements, the building should not cause harm to its occupants or the environment and must, for example, be structurally stable and fire safe. Sustainable development requires that the building does not cause unnecessary load or risk to the environment, for example in the form of energy use.

The significance of indoor climate for health and comfort has been emphasized in recent years. People spend about 90% of their time indoors. Therefore from the viewpoint of health, the quality of indoor air is even more important than outdoor air. Good indoor climate decreases the number of illnesses and sick building syndrome symptoms, and improves comfort and productivity. Good indoor climate is one of the most important goals of design and construction. Research and practice have shown, however, that the occupants are too often unsatisfied with the building. Complaints concerning modern buildings in respect of health and comfort are common all over the world.

This report is an overview of the performance criteria of buildings for a healthy and comfortable indoor climate. Most of the other requirements for buildings (e.g. safety, sustainability) have already been covered by international standards and guidelines and are not discussed in this document.

The quality of indoor climate is affected equally by heating, ventilation and air conditioning equipment, construction engineering, quality of construction work, building materials as well as the operation and maintenance of the building. Good indoor climate requires taking these aspects into consideration during all the stages of the design, construction and use of the building. Some of the problems may originate from the buildings themselves, some are caused by actions of the occupants or operation and maintenance of the buildings. Because of these multiple origins of the problem, it is important for owners and designers to specify the performance of the building and the construction process so that the building industry can prove through accepted procedures that the buildings meet the agreed performance criteria for health, and unnecessary claims are avoided.

The International Council for Research and Innovation in Building and Construction (CIB) established a task group with the International Society of Indoor Air Quality and Climate (ISIAQ) to deal with this problem. The result of this work is this CIB report " Performance criteria of buildings for health and comfort". It is intended to be used in the design and construction of healthier and more comfortable buildings and their mechanical systems. It also provides guidance for manufacturers of air-handling equipment and building materials who wish to produce better building products.

This report covers the main technical design and construction issues that are relevant in creating a healthy and comfortable indoor climate. In the beginning of each topic there is a short rationale and description of the essential requirements for healthy and comfortable indoor climate. These requirements are intended as minimum basis for setting more detailed performance levels. Some possible definitions of performance levels are presented next for each topic. These target and design values for indoor climate support the work of building owners, designers, equipment manufacturers, contractors and maintenance personnel. They can be referred to when writing specifications of construction and mechanical systems. For several parameters, the target and design values have been divided into three categories: basic, medium and high. This has been done to allow variation according to the needs of the client. The basic level usually reflects the current building practice in the industrialized countries. The medium and high levels show possibilities to improve the quality of the indoor climate to meet the needs of more demanding customers and sensitive occupants. The last chapter of each topic gives examples of more detailed numeric and descriptive criteria for indoor climate or examples of best building practices. These are usually innovative and high targeted techniques which have been proven effective but have so far applied only to a limited extent. Verification and measurement methods as well as some more detailed technical definitions have been included in the appendices of this document.

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1 INDOOR AIR QUALITY AND CLIMATE

1.1 Rationale and essential requirements for indoor air quality and climate

A standardized definition of Indoor Air Quality is not available. For the purpose of this work IAQ can be defined as:
the physical, chemical and biological properties that indoor air must have, in order :
- **not to cause or aggravate illnesses in the building occupants**
- **to secure high level of comfort to the building occupants in the performance of the designated activities for which the building has been intended and designed.**

From the above definition it clearly results that buildings with different use destinations may pose different requirements in terms of IAQ.

At the same time, as the "occupant population" may vary in composition (age, gender), density of occupancy (high, low), status of health (healthy or sick), genetic and biological predisposition to get ill (e.g. hypersensitive people, allergic people, etc.), it is virtually impossible to define an absolute set of criteria that would always meet the needs of any totality of occupants in every building.

Therefore the target values that will be discussed below have to be taken with caution and considered to be applicable only under the conditions and limitations mentioned for each of them.

1.2 Possible performance levels for indoor air quality

1.2.1 Target values of physical properties

Radon
Among physical agents, the most important health risk factor is represented by radon. Radon exposure in houses and other buildings is estimated to be responsible for a remarkable proportion of the lung cancers occurring in the population (5 to 15% depending on the local radon level in soil). Since radon is a genotoxic carcinogen for man, there is not a radon level to be considered "safe" in absolute and the desirable level should follow the "ALARA" principle (As Low As Reasonably Achievable).

The "Unit Risk" as defined by WHO (the probability of excess cancer for lifetime exposure to the unit value - in this case 1 Bq/m^3) is estimated to be 3-6 x 10^{-5} ; this means that a person living in a house with 50 Bq/m^3 has a lifetime lung cancer excess risk of 1.5-3 x 10^{-3}. The recommended level for remedial action in buildings is recommended by WHO to be 100 Bq/m^3, although various different levels (generally higher) have been set in national and international legislation.

Electromagnetic fields
The possibility that continuous exposure to low level electromagnetic fields causes long term health risk is still debated. Although countries or organizations have adopted regulatory or recommended values based on the precautionary principle, there is no scientific consensus as to the validity and justification of such values. At the moment therefore no specific target values are recommendable.

1.2.2 Chemical agents

The following table summarizes the guideline value recommended for a number of chemical air pollutants. The values should be read with the specifications that follow the table.

Table 1:1. Guideline values of some pollutants in the air

POLLUTANT	VALUES (mg/m^3)	REFERENCES
CARBON MONOXIDE	10 (8 hrs) 30 (1 hr) 60 (30 min) 100 (15 min)	WHO, 2000
NITROGEN DIOXIDE	0.2 (1 hr) 0.04 (annual)	WHO, 2000
PARTICULATE MATTER		
PM	No guideline values recommended	WHO, 2000
PM_{10}	0.05 (annual) 0.15 (24 hrs)	US EPA, 1996
$PM_{2.5}$	0.015 (annual) 0.06 (24 hrs)	US EPA, 1996
OZONE	0.12 (8 hrs)	WHO, 2000
VOCS		
Toluene	0.26 (1 week)	WHO, 2000
Benzene	UR: 6×10^{-6}	WHO, 2000
TVOCs	0.3	Seifert, 1990
Aliphatic hydrocarbons	0.1	
Aromatic hydrocarbons	0.05	
Halogenated hydrocarbons	0.03	
Terpenes	0.03	
Esters	0.02	
Aldehydes and ketones (excluding formaldehyde)	0.02	
FORMALDEHYDE	0.1 (30 min)	WHO, 2000

Particulate matter
After evaluating extensive epidemiological studies, WHO has concluded that even very low levels of particulate in the air (e.g. 10-20 $\mu g/m^3$ PM_{10}) are associated with an increased health risk in the population. Therefore in defining "health-based guideline values", no single figures are given. Instead WHO recommends to keep the exposure values as low as reasonably achievable. The table also shows the regulatory values adopted for outdoor air by US-EPA. They represent figures that ought not to be exceeded in any indoor condition.

VOCs
VOCs include many substances with different chemical structure and toxicity. Guideline values have been adopted only for some of them at national or international level.

Benzene, being a human carcinogen, does not have an health-based recommended limit but WHO has estimated a Unit Risk. Assuming an air benzene concentration of 5 $\mu g/m^3$, the individual lifetime excess risk of cancer would be 3 x 10^{-5}. A numerical value of benzene concentration in outdoor air is taken as a target value in some countries.

In the attempt at defining comfort target values for total VOCs and some subgroups of VOCs, tentative values were proposed by Seifert in 1990. As also specified by Maroni, these values have to be taken as indicative, order-of-magnitude values and not as absolute figures. Moreover, depending on the specific single compounds present in the mixture in the air, adverse comfort effects may occur even respecting these group values.

ETS

Environmental Tobacco Smoke (ETS) is a complex mixture of thousand chemical substances in particulate and vapour phase. Exposure to ETS is associated with an increased risk of lung cancer and several other health effects, ranging from irritation of eyes and mucosae to an increased risk of cardiovascular diseases. There is no evidence for a safe exposure level. Acute and chronic respiratory effects on children have been demonstrated even in houses with occasional smoking (0.1-1 µg/m^3 nicotine in the air). The unit risk for lifetime ETS exposure in a house where one person smokes is approximately 1 x 10^{-3}.

1.2.3 Biological agents

In epidemiological population studies, moisture damage and microbial growth in buildings have been associated with a number of health effects including respiratory symptoms and diseases and other symptoms. The health effects associated with moisture damage and microbial growth seem to be consistent in different climates and geographical regions. It has been shown with relatively good certainty that building-related moisture and microbial growth increases the risk of respiratory symptoms, respiratory infections allergy and asthma. The underlying mechanisms are irritation of mucous membranes, allergic sensitisation and non-specific inflammation. Also toxic mechanisms may be involved, especially in connection with toxin producing fungi and bacteria.

Examples of the concentrations of biological agents

The European Collaborative Action "Indoor Air Quality and its Impact on Man" in reviewing existing studies in homes and offices in 1993 classified the concentration of bacteria, fungi and allergens in air of the indoor environments according to the values shown in the following tables.

Table 1:2. Categories of bacteria concentrations (mixed populations - CFU/m^3) *observed* in homes and in offices (CEC, 1993)

CATEGORIES	HOMES	OFFICES
Very low	< 100	< 50
Low	< 500	< 100
Intermediates	< 2 500	< 500
High	< 10 000	< 2 000
Very high	> 10 000	> 2 000

Table 1:3. Categories of fungi concentrations (mixed populations - CFU/m^3) *observed* in homes and in offices (CEC, 1993)

CATEGORIES	HOMES	OFFICES
Very low	< 50	< 25
Low	< 200	< 100
Intermediates	< 1 000	< 500
High	< 10 000	< 2 000
Very high	> 10 000	> 2 000

Table 1:4. Categories of allergen concentrations *observed* in homes (CEC, 1993)

CATEGORIES	**Der p I (µg/g dust)**	**Der f I (µg/g dust)**	**Can f I (ng/g dust)**	**Fel d I (ng/g dust)**
Very low	< 0.5	< 0.5	< 300	< 100
Low	< 5	< 5	< 10 000	< 1 000
Intermediates	< 15	< 15	< 100 000	< 10 000
High	< 20	< 20	< 100 000	< 100 000
Very high	> 20	> 20	> 100 000	> 100 000

It is clear however that the above reported values and categories only represent the distributions of values that can be currently found in buildings and do not assume a specific meaning in terms of health risk. Neither can they be used as target values for healthy buildings.

1.3 Possible performance levels for thermal comfort

The environmental parameters which constitute the thermal environment are: Temperature (air, radiant, surface), humidity, air velocity and the personal parameters: clothing together with activity level.

Criteria for an acceptable thermal climate is specified as requirements to the general thermal comfort (PMV-PPD or operative temperature (air- and mean radiant temperature), air velocity, humidity) and to local thermal discomfort (draught (mean air velocity, turbulence intensity, air temperature) vertical air temperature differences, radiant temperature asymmetry, surface temperature of the floor). Such requirements can be found in standards and guidelines like EN ISO 7730, CR 1752 and ASHRAE 55-92.

Table 1:5. Three categories of thermal environment. Percentage of dissatisfied due to general comfort and local discomfort (CR 1752)

Category	Thermal state of the body as a whole		Local Thermal Discomfort			
	PPD %	Predicted Mean Vote	Draught Rate, DR %	Vertical Air Temp. difference %	Warm or Cool Floor %	Radiant Temperature Asymmetry %
High	< 6	-0.2 < PMV < + 0.2	<15	< 3	< 10	< 5
Medium	< 10	-0.5 < PMV < + 0.5	<20	< 5	< 10	< 5
Basic	< 15	0.7 < PMV < + 0.7	<25	< 10	< 15	< 10

The PMV and PPD indices express warm and cold discomfort for the body as a whole. But thermal dissatisfaction may also be caused by unwanted cooling (or heating) of one particular part of the body (local discomfort). Local thermal discomfort may be caused by draught, high vertical temperature difference between head and ankles, too warm or too cool a floor or by too high a radiant temperature asymmetry

It is mainly people at light sedentary activity who are sensitive to local discomfort. The diagrams and Table 4 apply to this group of people with a thermal sensation for the whole body close to neutral. At higher activities people are less thermally sensitive and consequently the risk of local discomfort is lower.

The criteria based on the three classes in Table 1:5 are in Table 1:6 listed for local discomfort parameters (radiant temperature asymmetry, vertical air temperature differences and floor surface temperatures.

Table 1:6. Possible categories for local thermal discomfort parameters.

Category	Vertical air temp. diff.*) K	Floor surface temperature °C	Radiant temperature asymmetry, K			
			Warm ceiling	Cool ceiling	Cool wall	Warm wall
High	< 2	19 - 29	< 5	< 14	< 10	< 23
Medium	< 3	19 - 29	< 5	< 14	< 10	< 23
Basic	< 4	17 - 31	< 7	< 18	< 13	< 35

*) between head and ancle height

1.4 Examples of numeric and descriptive criteria for thermal comfort

For the general thermal comfort (PMV-PPD, operative temperature) and air velocity the corresponding criteria for the three classes are listed in Table 1:7 for a couple of typical spaces. The optimal temperature is the same for all three classes but the acceptable range will change. For the design of heating systems and heat load calculations the lower value in the range should be used, and for cooling the upper value.

Table 1:7. Criteria for operative temperature and mean air velocity for typical spaces.

Type of building/ Space	Clothing Cooling Season (Summer) clo	Season (Winter) clo	Activity met	Category	Operative Temperature Cooling Season (Summer) °C	Heating Season (Winter) °C
Office	0,5	1,0	1,2	A	24.5 ± 0.5	22.0 ± 1.0
				B	24.5 ± 1.5	22.0 ± 2.0
				C	24.5 ± 2.5	22.0 ± 3.0
Cafeteria/ Restaurant	0,5	1,0	1,4	A	23.5 ± 1.0	20.0 ± 1.0
				B	23.5 ± 2.0	20.0 ± 2.5
				C	23.5 ± 2.5	20.0 ± 3.5
Department Store	0,5	1,0	1,6	A	23.0 ± 1.0	19.0 ± 1.5
				B	23.0 ± 2.0	19.0 ± 3.0
				C	23.0 ± 3.0	0 ± 4.0

Personal control

Only by personal control is it possible to compensate for individual difference in preference and then increase the level of acceptance. Table 1:8 shows the effect of changing different garments.

Table 1:8. Thermal insulation for garments and changes of optimum operative temperature necessary to maintain a thermal sensation of neutral when various pieces of garments are added (or removed) at light mainly sedentary activity (1.2 met), (ISO 9920).

Garment Description	Thermal Insulation clo	Change of Operative Temp. K
Panties	0,03	0.2
T-shirt	0.09	0.6
Short sleeves shirt	0.15	0.9
Normal shirt, long sleeves	0.25	1.6
Shorts	0.06	0.4
Normal trousers	0.25	1.6
Light skirts (summer)	0.15	0.9
Heavy skirt (winter)	0.25	1.6
Thin sweater	0.20	1.3
Light, summer jacket	0.25	1.6
Normal jacket	0.35	2.2

Humidity
The influence of the humidity on the preferred ambient temperature is in the comfort range relatively small (EN ISO 7730, ASHRAE-55-92). In EN ISO 7730 a humidity range of 30 – 70% RH is recommended, but mainly for indoor air quality reasons. In ASHRAE-55-92 the lower limit is a dew point temperature of 2 °C and the upper limit a 18 °C (winter) or 20 °C (summer) wet bulb temperature.

Draught
The air velocity in a space can lead to draught sensation, but may also lead to improved comfort under warm conditions. The draught model, which are included both in ASHRAE Standard 55 and ISO EN 7730, is listed below:

$$DR=((34-t_a)*(v-0.05)^{0.62})*(0.37*v*Tu+3.14)$$

where:

DR is the draught rating, i.e. the percentage of people dissatisfied due to draught;

t_a is the local air temperature in °C;

v is the local mean air velocity in m/s; and

Tu is the local turbulence intensity in per cent.

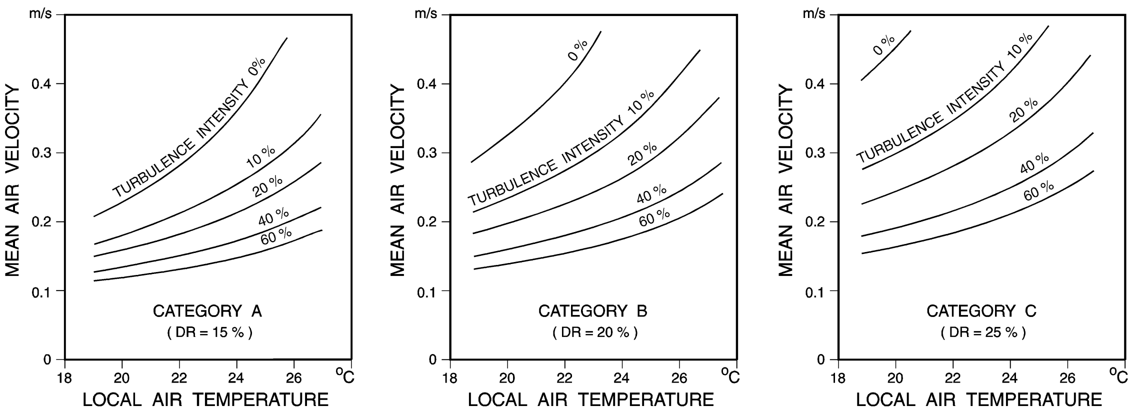

Figure 1:1. Mean air velocity as a function of local air temperature and turbulence intensity for the three categories of the thermal environment

1.5 Interactions between IAQ and thermal comfort

Whereas temperature is recognized as an important factor for human comfort, less attention have been given to the importance of humidity. This may be due to the fact that air humidity in the comfort range of temperatures has a minor impact on the thermal sensation of the human body.

Changing the air temperature or humidity of the indoor environment may change IAQ in at least two ways: The emission source strength of materials in a space may change and the perception itself of air with a given chemical composition may change. The dependency of temperature and humidity on emission of chemicals from materials is well known. A higher temperature is most likely to increase the emission and elevated air humidity may increase the emission rate of different chemicals, such as formaldehyde, from some types of materials.

Recently there has been increased attention to the direct effect of temperature and humidity on human perception of the IAQ. It has been documented that air temperature and humidity has a strong and direct impact on the perception of air quality. Several studies have found that acceptability of air decreased with increasing air temperature and humidity. A cooling of the mucous membrane during inhalation appears to be desirable. Temperature and humidity change the energy content of the inspired air which results
in a changed cooling of the respiratory tract. At a high air temperature and humidity, an insufficient cooling may be interpreted as a local warm discomfort in the respiratory tract and, in turn, lead to the inhaled air being perceived as unacceptable.

Keeping the indoor air dry and cool as oppose to humid and warm may not only improve the perceived air quality, but also have an important impact on the amount of energy used for ventilation. As an example of this, Fang et al. (2000) demonstrated that reducing the ventilation rate from 10 to 3.5 L/s per person in an office space can be compensated for by reducing the air temperature and humidity from 23°C and 50% RH to 20°C and 40% RH so as to avoid deteriorating the perceived air quality.

1.6 Special requirements for allergic and hypersensitive people

We spend approximately 90% of our time indoors and the indoor environment can have an effect on both our health and productivity, Wargocki et al. 1999, Fisk, W.J. 2000, etc. Allergic diseases have increased sharply during the past few decades in countries with a Western lifestyle. An increased number of the new cases and prevalence of allergies and other hypersensitivity diseases have been linked with changes in the indoor environment. Allergic or hypersensitive persons are most likely to perceive alteration of the indoor environment earlier, than non-allergic or non-hypersensitive persons, which Lundin (1999) confirmed. Lundin took into account the students´ perception of the indoor air quality, cleaning, thermal comfort, odor/smell, environmental tobacco smoke, lightning, noise, dust and dirt. It is not technically or economically possible to adapt all buildings to every known kind of allergy or hypersensitivity. Buildings must therefore be adapted individually or adapted to a prescribed minimum level. Hypersensitivity caused by electric and magnetic fields are relative unexplored and therefore not considered here. The following discusses some of the factors of healthy buildings related specifically to allergic patients. Construction of allergy safe homes and buildings are discussed in Björck (2000a, 2000b), Björck (2001), Hult and Persson (1991), Jansson and Sörensen (1998) and Vaarning and Landerslev (1998).

Location and surroundings of the house
When locating an allergy adapted house consider e.g. air pollution and allergens. Air pollution, such as particles and SO_2 or NO_2 e.g. exhausted fumes, should be avoided in the immediate surroundings. The house should not be located near allergen sources, e.g. horse stable, to avoid the spreading of allergens to the indoor air. When planning the immediate surroundings of the house consider pollen and strong scents from trees or other vegetation. Avoid wind pollinating and strong smelling vegetation. Choose instead insect pollinating vegetation that do not have a strong scent.

Ventilation
There exist a number of measures to minimize the content of air pollution and allergens in the indoor air that must be taken into account when choosing a ventilation system. The supply air terminal device should be equipped with at least class F7 filter considering e.g. pollen. It is important to maintain the installed filter and a clean ventilation system. Physically dry air or contaminated air can cause increased problems with e.g. dry skin and mucous membranes, and therefore are sensitive persons affected. A separate air purifier can be used if a cleaner air in a certain room is desirable, e.g. in the bedroom while the pollen season gives the pollen allergic person a hard time.

Building materials
A common upraise to chemical emission is incorrect use or incorrect handling of materials. Since we do not know exactly which compounds that cause negative health effects, low emitting materials should be chosen. In Finland M1 classified material by FiSIAQ can be chosen. In Sweden materials recommended by the Swedish Allergy and Asthma Associations can be chosen. In Denmark and Norway ICL (Indoor Climate Label) labeled material can be chosen. Choose solid and well-known surface materials like wooden flooring (preferably fabric lacquered), ceramic wall tile and clinker together with wallpaper, which are easier to clean and low emitting. Always demand a declaration of contents regarding used building material if a person

is specifically sensitive against some substance e.g. formaldehyde.

Dampness
Bornehag et al. (2001) have found strong associations between damp buildings and health and therefore it is important that allergy adapted houses do not contain health hazardous microbiological growth.

Heating system
The thermal climate affect allergic persons since they can be sensitive to high respectively low temperature and the change of temperature. A comfortable indoor temperature is approximately between 20-24°. Under floor heating is believed to decrease the content of air-borne mould spores and eliminate radiators at the same time. If radiators is unavoidable they should have a smooth surface and installed 3-4 cm from the wall, which facilitate the cleaning behind the radiator.

Layout of the house and furnishing
The house can be divided into three different cleaning zones that symbolize the degree and quality of exacting cleaning. In a home the "dirty zone" consist of the hall and kitchen, while a bedroom should belong to the "clean zone", free from dirt and allergens. The bathroom or toilet is "half-clean". The cleaner a zone is the better it is to place it a bit from the entrance to avoid that dirt is brought there easily. To avoid problems for nickel-allergic persons make sure that there are no chrome or nickel contact surfaces. Linen cupboard or wardrobe can help to maintain clothing free from allergens. Observe that wardrobes, cabinets and cupboards should be of full height up to the ceiling. to avoid dust collecting surfaces that is difficult to reach and clean. For an easier cleaned bathroom install a wall suspended toilet, a bathtub with no front panel and cabinets instead of shelves. An entrance door without a letter slid prevents unwanted leakage of polluted air from the stairway, increased security and better sound insulation. A carpet in front of the door can reduce incoming dirt and a cabinet for e.g. shoes can make the floor easier to clean. A separate own washing machine can eliminate problems with other peoples perfumed or animal dander contaminated clothes. A sink cabinet with no base and removable pedestal in the kitchen can make the kitchen easier to clean. Extra workspace and food storage options can make food preparation easier for a food allergic person. Choose furniture's with high legs (easier to clean below), removable and washable upholstery, and bookshelves with glass doors. Also choose curtains and carpets that are easy clean. Finally a central vacuum cleaner can improve the cleaning.

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2 VENTILATION

2.1 General requirements for ventilation

Ventilation (outdoor air flow) has to be adequate to remove and dilute the pollutants indoor, and provide acceptable level of contaminants in the indoor air. Control of the pollutant sources, however, shall be considered as the first alternative to improve indoor air quality. Ventilation shall be energy efficient and arranged so that it does not deteriorate indoor air quality and climate, and does not cause any harm to the occupants or to the building. Ventilation rates should be based on the pollution loads and use of the building.

2.2 Specific criteria for ventilation systems

The ventilation rates should be based on pollution load of the ventilated space or building.

An example how the ventilation rates could be specified by pollution load is given in the Table 2:1. Alternate method is given in Ashrae 62n.

Table 2:1. An example of ventilation rates for offices depending on the pollution load in three categories (CEN 1752)

Category	Occupants only		Low-polluting materials		High-polluting materials	
	L/sm^2	cfm/ft^2	L/sm^2	cfm/ft^2	L/sm^2	cfm/ft^2
A (high)	1	0.20	2	0.40	3	0.60
B (medium)	0.7	0.14	1.4	0.28	2.1	0.42
C (basic)	0.4	0.08	0.8	0.16	1.2	0.24

The minimum ventilation rate is 10 -15 L/s[1] per person, which is approximately 1 L/s per m^2 in office buildings with normal occupant density, and 0.5 ach in living spaces of the residential buildings[2].

Carbon dioxide concentration can be used as surrogate of ventilation rates, but its use to measure ventilation is uncertain as its concentration in buildings seldom reaches steady state due to variations in occupancy, ventilation rates and outdoor air concentration. Steady state values of carbon dioxide concentration can be calculated from CO_2 generation of 0.00567 L/s per occupant in office buildings.

Odour can also be used be used as a criterion for indoor air quality. More information is given in CEN report 1752 and Ashrae Standard 62.

Ventilation air should be distributed and used effectively in the building

- Ventilation air should be distributed to the rooms of the building according the design and use of the rooms.
- This means in practice that system should designed and constructed so that the air flows can be measured and balanced.
- Ventilation air should reach to the breathing zone of the rooms as soon as possible after entering to the room

[1] Reviews by Seppanen et al. (1999) and Wargocki et al. (2002) indicate that adverse effects of indoor air may be alleviated with ventilation rates up to 25 l/s per person in office buildings with current construction practice.
[2] Conclusion by Wargocki et al. 2002 concerning dwellings in cold climate

- o This does not allow any short circuiting of ventilation air flow to exhaust opening, and minimum air change efficiency = 50% (definitions of ventilation effectiveness are clarified in the Table 2:2).

Table 2:2. Values of ventilation effectiveness for various flow patterns.

Room flow pattern	Air change efficiency	Air change effectiveness (ASHRAE 62) Ventilation efficiency (CEN 1752)
complete mixing	50%	1
piston flow	100%	2
displacement flow	50-100%	1-2
short circuiting flow	< 50%	0-1

- Ventilation air should remove the pollutants from the room effectively.
    - o This requirement can be expressed with minimum pollutant removal efficiency which is > 1 when the pollutant concentration of exhaust air is greater that room air in breathing zone.

- Minimum ventilation rates should not vary significantly independent from the pollution loads.
    - o Significant variations which may be harmful to health may be caused by changes in outdoor conditions (e.g. effect of temperature and wind on natural ventilation or temperature controlled VAV-systems with no minimum flow rate)

Air used for ventilation should be clean

- Outdoor air used for ventilation should be clean from harmful
    - chemicals, requirements for outdoor air can be given as in CEN 13779,
    - particles, requirements for outdoor air can be given as in CEN 13779 or indirectly specifying requirements for air cleaning as Chapter 3, and
    - odours, requirements for outdoor air can be given as in CEN 13779.

- Air handling system should not deteriorate the quality of the supply air.
    - o The quality of ventilation air should not be deteriorated in air handling system, but as the measurements show deterioration may happen[1], and the requirements have to be set for cleanliness of components in air handling system and the system itself (an example how this can be done is described in Chapter 3 and FiSIAQ 2001). These requirements should be set for new systems and those in use (VDI 6022).

Ventilation air should not cause any harmful effects

- Ventilation air should not cause unacceptable thermal discomfort due to its temperature, velocity or flow direction
    - o The criteria for draft are described in Chapter 1.3.

- Ventilation system should not cause acoustical discomfort
    - o Noise generated by ventilation may cause discomfort, adverse health effect or difficulties in oral communication, but it can also be used to mask more disturbing and annoying sounds like conversation on phone in open space offices. An example how the criteria for noise levels are given based on thee consideration is given in CEN 1752.

- Ventilation system should not cause damage to building structures or operation

[1] see e.g. Bluyssen et al. (2001)

  - Ventilation system may create pressure differences over building structures that may lead to unwanted draft close to doorways, difficulties in operation of doors, and moisture transport to the structures (moisture problems are dealt more in Chapter 5). An example of limit values for pressure differences are given CEN 13779.

- Ventilation system should not spread the pollutants from structures, ground, outdoor air or from sources indoors
  - Ventilation should enhance the air in the building to flow from clean areas to less clean areas. Ventilation should remove the pollutants from their source (local exhaust). Pressure differences created by ventilation shall not increase significantly the polluted soil air to enter to the building (radon and other harmful soil gases). Ventilation should not either draw the pollution from local sources outdoor into the building (location of outdoor air intake). Descriptive guidelines to avoid these problems are given in CEN 13779.

Ventilation should be provided to a building in an energy efficient way

- Air for ventilation should be moved in an energy efficient way.
  - Natural forces should be used for that as much as feasible. The use of electricity by fans should be limited. A guideline value of 2.5 kW per m^3/s (including the supply and exhaust air fans) is used in Scandinavian guidelines.

- Heat recovery from the ventilation air should be encouraged.
  - Energy density in the exhaust airflow is high, and heat recovery is often economic way to reduce the energy and operation cost of ventilation. The heat recovery becomes more feasible with high air flows and low outdoor temperatures. Limit values can be set for minimum efficiency of heat recovery and size of the air handling system where the heat recovery shall be applied. (Finnish building code requires that 30% of heating of all exhaust air flows of a building shall be used for heating.)

Ventilation should be controllable by the occupants

- Individual control of ventilation should be encouraged
  - Individual control of ventilation improves the user satisfaction. The means that individual control should be provided if possible. Operable windows provide one way to control ventilation and should be provided, particularly, if climatic conditions and location of building are favorable for natural ventilation.

2.3 Criteria for design and documentation

- Criteria for the designer
  - Design of ventilation requires professional skills. Criteria for the responsible person for the design can be set as in the US (professional engineers examination) or like in Finland where building inspector has to check the professional skills, training and experience of principal designer.
- Criteria for documentation
  - One criteria of proper design of ventilation is the documentation of design that is at any rate needed during the construction and operation of the building. The requirement for documentation may include design calculations, drawings, and technical specifications.

2.4 Construction criteria

- Criteria for the contractor who installs the ventilation system
    - Installation of ventilation requires professional skills. Criteria for the responsible person for the installation can be set as in Finland where building inspector has to check the professional skills, training and experience of the person in charge of the installation.

- Quality control in construction process
    - Tests, measurements and inspections may improve the quality of the installation, as well as the inspections by the building inspectors. Guidelines for commissioning process have been developed by engineering associations in Europe (REHVA) and in the US (ASHRAE).

2.5 Criteria for operation

- Criteria for facility management and operation personnel
    - An example how the requirements can be set is given in VDI 6022. Checklist for the hygienic operation and maintenance of air conditioning system is given in appendix.

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3 CLEANLINESS OF SUPPLY AIR

3.1 Rationale and essential requirements

The quality of supply air is affected by the air handling system. **The air handling system should not deteriorate the quality of the air supplied indoors**. For this reason the components of the air handling system should be clean and constructed so that good quality of the air supplied via the air handling system can be maintained during the operation of the air handling system. In order to maintain reliable operation of the system **the outdoor air should be filtered**.

3.2 Cleanliness of ventilation system and components

3.2.1 Rationale and essential requirements

The essential criteria for the cleanliness components of air handling systems are:

- **The components shall not increase the concentration of harmful substances in supply air**
- **The components shall not emit the harmful substances into supply air**
- **Component shall be easy to clean (no obstructions for cleaning)**

3.2.2 Possible performance levels

The cleanliness of ventilation system consists of several factors (particles, gases, odors) and it is very difficult to describe measurable performance levels for it. The following definitions are from the Finnish Classification of Indoor Climate 2000 (FiSIAQ 2000).

<u>High level of cleanliness of ventilation system</u>

- The supply air ducts and fittings shall be manufactured using clean components or the components shall be cleaned at the construction site to satisfy the same requirements (see 3.2.3 for examples of these requirements).
- The sealing materials shall have low emissions.
- The average amount of dust on the inner surface of a new air-handling system shall not exceed 1.0 g/m^2 when measured with the filter sampling method (Pasanen et al. 1999).
- Return air shall not be used except in air-handling units serving only one dwelling.
- The supply air of the air-handling unit shall be cleaned with a filter whose dust removal efficiency fulfils the requirements of at least European class F8/EU8 and a pre-filter whose dust removal efficiency fulfils the requirements of European class G3/EU3.

<u>Medium level of cleanliness of ventilation system</u>

- The supply air ducts shall be manufactured using clean components or the components shall be cleaned at the construction site to satisfy the same requirements (see 3.2.3 for examples of these requirements).
- The average amount of dust on the inner surface of a new air-handling system shall not exceed 2.5 g/m^2 when measured with the filter sampling method (Pasanen et al. 1999).
- Return air may be used only if it is extracted from spaces with similar or better cleanliness. The return air shall be filtered with a filter whose dust removal efficiency fulfils the requirements of at least European class F7/EU7.
- The supply air of the air-handling units shall be cleaned with a filter whose dust removal efficiency fulfils the requirements of at least European class F7/EU7.

3.2.3 Examples of numeric and descriptive criteria for the cleanliness of some major components of air handling system

General requirements

- Components shall be cleanable
- The components shall not be harmful for the commonly used cleaning methods
- Components shall stand the specified cleaning at least 10 times, without extra emission of fibers or other pollutants
- No adhesives of sticky labels shall be inside the components
- The surface structure and shape of the components shall not enhance the accumulation of dust
- Dampers and other components can easily to be positioned in the original position after the cleaning

Numeric criteria for ducts

- Odor acceptability* better than 0.05
- Oil concentration on interior surface**<0.05 g/m^2
- Release of mineral fibers*** <0.01 f/cm^3
- Dust concentration on interior surface**** <0.5 g/m^2

*) Acceptability (untrained panel) of air quality passing through the component
**) Collection of oil with a solvent and IR-spectrometry analysis (Pasanen et al. 1999)
***) Visual counting with microscope
****) Gravimetric method with filter collection of the sample (Pasanen. 1998)

Duct linings and sound dampers

- Only low emission materials used inside the ductwork
- Avoid inner duct lining in air ducts and air handling units
- If the lining is used it shall stand the cleaning at least 10 times

Humidifiers

- Humidifiers shall automatically shut down with fan
- Humidifiers shall be dry during shut down period
- Only hygienic, desalinated, odorless steam or water shall be used
- Humidifiers shall be equipped with droplet eliminators
- Humidifiers shall be equipped with drip pan
- No condensate shall enter the ductwork

Heating coils

- Must be washable
- Drainage of washing water shall be provided
- Casing shall stand the washing

Cooling coils

- Must be washable
- Drainage for the condensed water shall be provided
- Drainage of washing water shall be provided
- Casing shall stand the washing
- Drained drip pans required

Heat recovery units

- Leakage from exhaust air to supply air is less than 6% or the pressure differences over the unit set to prevent leakage from exhausts air to supply air
- Drainage of possible condensed water
- Heat transfer surfaces must be easy to clean
- Negligible emissions form heat transfer surfaces
- Use purging sector in rotating regenerative heat recovery units

Terminal units

- Terminal units shall be easy to clean
- Terminal units shall not enhance resuspension of dust from room surfaces
- Water shall not condense in terminal units
- The release of fibers from terminal units shall be negligible

Outdoor air intake

- Entry of rain water or snow to the air handling system prevented
- Equipped with an easy-to-clean protection net against birds and debris
- Does not allow penetration of rain water into the wall structure between the casing and wall surface
- Air intakes below street level and in busy streets to be avoided
- Air intakes must be molest proof, not accessible for the public and easy accessible for maintenance.
- Short-circuiting of exhaust air, flue stacks, cooling towers etc. must be prevented.
- The distance between air intake and air filter should be as short as possible and accessible for cleaning.

Outdoor air chamber

- Thermally insulated in cold climate
- Easy to clean surfaces
- Vapor barriers in the structures
- Equipped with drainage

Outdoor air dampers

- Thermally insulated in cold climate
- Freeze protected in cold climate
- Air tight

Fans

- Motors and power transmission of fan shall not emit harmful substances into the air flow
- Impellor of the fan shall be cleanable

Ducts
- Easy to clean, preferably round ducts
- Clean and free from oil
- No inner insulation permitted
- Avoid air turns in rectangular ducts
- Cleaning strategy is part of the design
- Inspection and cleaning holes to be provided in the factory

3.2.4 Examples of descriptive cleanliness requirements of the HVAC systems during the construction phase

When transporting air-conditioning systems from the workshop to the building site, all openings shall be sealed with a protective cover (if necessary protect the equipment with a tarpaulin). This also applies to equipment which due to its size is delivered in separate sections. All openings shall also be covered during interruptions in installation or if heavy dust develops at the installation site.

Depending on the hygiene requirements, the air ducts are to be protected against contamination during transport and storage at the building site, or to be cleaned. DIN EN V 12097 gives three requirement levels for the cleanliness of air ducts (table 3.1).

Table 3:1. The requirement levels for air ducts according to DIN EN V 12097

Level	Packing from works	Protection during work	Protection during storage	Cleaning on site	Blanking off air duct openings on site
Basic	No	No	No	No	Rising lines only
Standard	No	No	Yes	Yes	Yes
High	Yes	Yes	Yes	Yes	Yes

3.3 Filtering in relation to outdoor air quality

3.3.1 Rationale and essential requirements

The objective of air filtering is to prevent particulate matter present in the outdoor air from entering into the indoor environment and, in the case of recirculated air, to capture the particles generated indoors. There are a number of factors that need to be considered when designing an efficient filtration system for the specific conditions under which it will operate:

- Size range of particles in outdoor air
  Airborne particulate matter is a mixture of particles of different sizes and composition generated by a large number of natural and anthropogenic sources. Particle sizes in the air range from nanometer to tens of micrometers. Different particle sizes usually imply different sources and very different composition. Particles smaller than 1 µm usually originate from combustion gas to particle conversion or nucleating processes while larger particles usually result from mechanical processes such as cutting, grinding or road dust resuspension. Small particles typically contain a mixture of components including soot, acid condensates, sulfates and nitrates, as well as trace metals and other toxins. While some processes result in the generation of particles with a broad size distribution covering both fine and coarse ranges, in most cases smaller and larger particles result from different generation processes.

- Concentration of particles in outdoor air and its time variation
  Concentration levels of particulate matter in outdoor air around a building envelope vary significantly and depend on the strengths of the outdoor sources, patterns of operation of the sources, the distance between the sources and the building and meteorological conditions, particularly wind direction.

- Filter efficiency

The main filtration mechanisms include diffusion, interception, and impaction. These mechanisms are not equally efficient in all particle size ranges and in particular, the diffusion process is the most efficient for smaller particles and becomes of negligible importance for the particle size range above 0.5 µm, while impaction and interception play almost no role for smaller particles and become significant for particles larger than about 0.5 µm (Willeke and Baron, 1993). The overall filtration efficiency, which is the sum of efficiencies of individual processes, is the lowest for particles in the range between 0.1 and 0.2 µm, as none of the processes mentioned above is very efficient in this region.

3.3.2 Possible performance levels for filtering

These performance levels for filtering describe the output of a filtering system. In designing the system, one should take into consideration the principles described in 3.3.1, 3.3.3 and Appendix 5.

<u>Basic level</u>
The basic level for filtering protects the ventilation system clean from harmful accumulation of dust and particles.

<u>Medium level</u>
The medium level of filtering prevents the ingress of pollen and city dust, excluding fine particles, to the supply air.

<u>High level</u>
The high level of filtering prevents the ingress of fine particles to the supply air.

3.3.3 Examples of design and operation of an efficient filtration system in relation to outdoor pollution

Taking the dependency of particle size on the sources from which they originate and the variation of filtration efficiency with particle size, in order to optimize filtration efficiency it is important to gain knowledge on both size distribution of particles in the air to be filtered and the relationship between filtration efficiency and particle size. In addition, assessment needs to be made about the expected concentration level of particles around the building envelope and its time variation. This information is necessary for selecting the most suitable type of filters for the type (mainly size) of particles that dominate in the outdoor air. In particular, most of the media filters are not efficient for small combustion particles, while they could be quite adequate for larger particles present in the air. For example it has been reported that the efficiency of a pleated paper filter for particles below 0.1 µm is smaller than 5%, while the efficiency of the same filter for particles larger than 1 µm and 2 µm are greater than 50% and 90%, respectively (Jamriska et al., 2001; Hanley et al., 1994). On the other hand, electrostatic filters are very efficient for small particles, but are more expensive, and thus there would be little justification for employing them in an environment dominated by large dust particles. For example for particles smaller than 1 µm, the fractional collection efficiency of a two-stage electrostatic precipitator at flow rates below 560 L/s was found to be over 95% (Morawska et al., 2001).

3.3.4 Examples of hygienic requirements for filters

- Bypass of air less than
  6% below G5
  4% F6
  2% F7
  1% F8
- Release of fibers less than 0.01/cm^3
- No harmful biocides in the filter media
- Easy to replace
- No contact of filter media with the bottom of casing of the air handling unit
- Keep air filters dry thus avoiding penetration of moisture in the air handling system and eventually freezing of the air filter
- Avoid overload of air filters
- Apply odor filters, air washers or smog filters in case of poor outdoor air quality

3.4 Design for maintenance and operation

3.4.1 Rationale and essential requirements

Air-conditioning systems shall be designed and installed so that it is possible to operate and maintain it in such a way that the hygiene requirements also are permanently complied with.

3.4.2 Examples of numeric and descriptive criteria

<u>In general for all components</u>

- Openings and space for the inspection and cleaning shall be provided in all components.
- All interior surfaces shall be smooth, sharp-edged curves and transition pieces or self-tapping screws in the walls should be avoided.
- All connections, edges tapes etc. shall not be attached and sealants with high emission materials.
- All stiffeners and other fittings shall be installed in such a way that deposits of dirt are prevented and cleaning can be carried out.

<u>Ducts</u>

- flexible air ducts are to be limited because of the difficulty of cleaning
- ducts shall be cleaned after the manufacturing to limit oil residues to the extend mentioned above
- insulation (outside) is necessary where temperatures may fall short of the dew point
- prior to the first operation, all parts in contact with the airflow shall be checked for complete cleanliness and recleaned if necessary
- service opening for inspection and cleaning have to be installed
- inspection intervals may take into account certain system specific aspects such as level of outdoor air pollution, type of system (supply, recirculating), filtration efficiency, height of outdoor air intake
- inspection points are to be chosen in areas within the duct system which offer particularly favourable conditions for the survival of micro organisms (behind humidifiers, in areas of dew point conditions such as cold deck surfaces) and where the highest dust load can be expected (beginning of duct, particularly where filters of low class are installed or in systems older than 20 years)
- inspection procedures shall start with a visual check on dust deposit thickness, i.e. is metal duct surface visible; if not, then quantitative measurement of dust required; the visual check should include an spots of possible microbial contamination
- measurement areas at the inspection points shall be chosen as follows:
  - in rectangular ducts on the bottom surface at half width
  - in circular ducts on the bottom around the lowest point
- is a distance of the inspection point to obstacles (e.g. elbows) or fittings of > 5 HD not possible. generally those areas of visibly highest dust concentration should be investigated
- ducts smaller than 71 mm in diameter (circular) or 120 mm in width (rectangular), where no service openings can be installed may be visually inspected with an endoscope inserted through a hole in the size of those drilled for measurement of air flow

<u>Filters</u>

- Two filter stages are recommended. The first filter stage should use F7 and the second one F9 (VDI 6022 Part 1)
- Use a new filter that is low-polluting;
- Check the pollution effect regularly in sensory, chemically and biological terms;
- Change the filter when:
  - It does pollute instead of cleaning the air:
  - When maximum pressure difference is exceeded;
  - At least after 1 year in low polluted areas (sub-urban, country-side), 0.5 years in polluted areas (town);
- Keep the filter material as dry as possible; (Heater in front of the first filter)
- Possible new solutions:
- Additional drying of incoming air (with a pre-heater);
- Two stage filtering, with frequent change of first filter.

Humidifiers

Table 3:2 shows the given levels for humidifier water in HVAC-systems (Müller et al., 1999, VDI 3803).

Table 3:2: Given levels for humidifier water in HVAC-systems (VDI 3803).

composition			HVAC for normal climatic demands	HVAC for areas of data processing	HVAC for sterile and clean rooms
appearance		-	clear, colourless and without sediment		
ph-value		-	between 7 and 8.5		
complete salt content	CSC	g/m^3	<800	<250	<100
electric conductivity		mS/m	<100	<30	<12
		µS/cm	<1000	<300	<120
calcium	Ca^{++}	mol/m^3	>0.5		-
		g/m^3	>20		-
carbonate hardness	CH	mol/m^3	<0.7		
		°d	<4		
carbonate hardness	CH	mol/m^3	<3.5		
by the stabilisation of hardness		°d	<20		
chloride	Cl^-	mol/m^3	<5	-	-
		g/m^3	<180	-	-
sulphate	SO_4^{2-}	mol/m^3	<3	-	-
		g/m^3	<290	-	-
consumption of $KMnO^4$		g/m^3	<50	<20	<10
number of germs		ml^{-1}	<1000	<100	<10

Highest level of germs in the water is 1000 CFU/ml
Legionella 0 CFU/ml
Hardness 7° dH

Spray nozzle humidifiers and evaporative humidifiers

- A shut down control system shall ensure that the humidifier chamber run dray after a shut down.
- A water temperature control system shall ensure that the humidifier runs dry and is refilled with new water when the water temperature exceeds 20°C.
- In case that there is an oil film on the water surface, the water must be drained and the humidifier must be cleaned immediately (for oil film is not allowed).
- The desalinization must take place with an agent which is not smelling.
- The ducts after the demister must be checked for humidity.

Steam humidifier

- The water quality must be as described for the spray nozzle humidifier
- The desalinization must take place.
- The desalinization medium is not allowed to smell in order to improve indoor air quality.
- In case that there is an oil film on the water surface, the water must be drained and the humidifier must be cleaned immediately.
- The water in the water tank must be handled like that of spray nozzle humidifier water. It needs also a shut down control.
- The humidifier shall automatically shut down as soon as the HVAC-system is shut down or fails.
- A shut down control system shall ensure that the humidifier chamber runs dry after a shut down.
- A water temperature control system shall ensure that the humidifier runs dry and is refilled with new water when the water temperature exceeds 20°C.

Ultrasonic humidifier

- For Ultrasonic humidifier only demineralized water may be used in order to function correctly. The demineralization device is installed in the disperser to keep the oscillator circuit board free from mineral precipitation for as long as possible. The water must be clear, colourless and without sediment. Cleaning is relevant if the water looks unclear.
- The water in the water tank must be handled like that of spray nozzle humidifier water. It needs also a shut down control
- The desalinization medium is not allowed to smell in order to improve indoor air quality.
- The humid air from the ultrasonic humidifier shall contain no substances which are harmful to health. Further investigations about the reaction of human being on different desalinization media are required.
- In case that there is an oil film on the water surface, the water must be drained and the

humidifier must be cleaned immediately (for oil film is not allowed).

Coils
- New coils without oil residuals have to be used!
- There must be a drain for the condensate.
- The condensate is allowed to contain no more than 1000 CFU/ml. (Similar to the water in humidifier)
- The visible growth of moulds on the coil surface is not allowed.

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4 EMISSIONS FROM BUILDING MATERIALS

4.1 Rationale and essential requirements

The building materials are considered to be the principal sources of indoor air quality in addition to those caused by humans and their activities. It has been necessary to restrict the emission from new materials in order to provide buildings with more comfortable or even healthier indoor air quality. Emission from building materials is due to solvents, additives necessary for the manufacturing process or for the optimizing the service properties of each specific material, process residues or chemical reactions in the materials during the processing or a result of mishandling of them during the building phase, faulty planning of structures causing chemical attacks on materials resulting in irreversible emissions due to degradation. Oxidation of materials with due emissions may also occur during their life cycle in the building the strength and chemical type depending of the chemical nature of the degrading material.

It is evident that excessive emission from materials may cause comfort and health problems indoors even as relatively low concentrations.

4.2 Possible performance levels for material emissions

In various countries procedures for restricting the emissions have been established. In Sweden there are industry standards (Swedish trade standard for flooring materials), in Germany restrictions for emissions of flooring products have been established (GEV), in Denmark a label has been established (The Indoor Climate Label), and in Finland a Classification of Indoor Climate, building works and finishing materials was established in 1995. These evaluation procedures and criteria differ from each other in the coverage of building materials and products and criteria for evaluation of the emissions.

In aiming at a desired indoor air quality class, the materials used shall have a product specification presenting emission class data, the possible limitations for the use of the materials and requirements for the environmental conditions where the material is applied, such as temperature and humidity tolerances.

The Classification of Building Materials presents the requirements for materials used in ordinary workspaces and residences. The goal of the Classification of Building Materials is to enhance the use of low-emitting products so that material emissions do not increase the need for ventilation and thus provide a cost effective and yet healthy and comfortable indoor environment.

The emissions are characterized both in chemical and sensory terms, because the analytical methods are not able to cover all emissions which, however, are noticed by human nose and may be cause for complaints of poor indoor air quality.

4.3 Examples of numeric and descriptive criteria for material emissions

The Finnish classification system (Classification of Indoor Climate 2000) consists of three parts: building design, structural design and appropriate material choice. All these processes affect the material emission behavior in the final building. The importance of the design and building phases are emphasized and guidance is given especially to cover moisture prevention and moisture characteristics of materials. The Classification supplements The National Building Code of Finland. General Requirements for Quality in Construction Work. Model Specifications for Constructions.

The classification functions through giving target values for indoor air quality in chemical terms and odor, Table 4.1, and emission requirements for building products. Fulfilling this guidance and emission requirements the desired indoor air quality can be reached within one year in a new building.

Table 4:1. Examples of building material related target values of indoor air quality.

		Unit	Indoor climate category Maximum values		
			S1	S2	S3
Ammonia and amines	NH_3	µg/m³	30	30	40
Formaldehyde	H_2CO	µg/m³	30	50	100
Volatile organic compounds	TVOC	µg/m³	200	300	600
Odor intensity (intensity scale)			3	4	5.5

The target values presented in the Table may be used as reference values for the measurement and inspection of indoor air quality, but this is necessary only in special cases. The inspection of whether the target values of indoor air quality have been fulfilled should be carried out within six to twelve months after the handing over of the building. The target values of the specified compounds do not guarantee the perfect healthiness of the room air because concentrations below the target values may cause symptoms in sensitive persons. On the other hand, exceeding the target values does not, according to present knowledge, lead to immediate health impediments.

In aiming at a desired indoor air quality class, the materials used shall have a product specification presenting emission class data, the possible limitations for the use of the materials and requirements for the environmental conditions where the material is applied, such as temperature and humidity tolerances.

The Classification of Building Materials presents the requirements for materials used in ordinary workspaces and residences. The goal of the Classification of Building Materials is to enhance the use of low-emitting products so that material emissions do not increase the need for ventilation and thus provide a cost effective and yet healthy and comfortable indoor environment.

The emissions are characterized both in chemical and sensory terms, because the analytical methods are not able to cover all emissions which, however, are noticed by human nose and may be cause for complaints of poor indoor air quality.

The Classification of Building Materials has three emission classes, emission class M1 corresponds to the best quality and emission class M3 includes materials with the highest emission rates.

Emission class M1 is designated for emission-tested materials whose emissions fulfill the requirements of Table 2 Emission class M2 is designated for emission-tested materials whose emissions fulfill the requirements of Table 3. Emission class M3 includes materials whose emissions exceed the values specified for materials in category M2. Materials that have not been tested shall not be granted a classification label.

Table 4:2. Requirements of emission class M1.

The emission of total volatile organic compounds (TVOC) shall be below 0.2 mg/m²h. A minimum of 70% of the compounds shall be identified. The emission of formaldehyde (H_2CO) shall be below 0.05 mg/m²h. The emission of ammonia (NH_3) shall be below 0.03 mg/m²h. The emission of carcinogenic compounds belonging to category 1 of the IARC monographs (IARC 1987) shall be below 0.005 mg/m²h. The material is not odorous (dissatisfaction with odor shall be below 15%). Plasters and tiling products, leveling agents, putty, mastics, fillers, screeds and renders shall not contain casein.

Table 4:3. Requirements of emission class M2.

The emission of total volatile organic compounds (TVOC) shall be below 0.4 mg/m²h. A minimum of 70% of the compounds shall be identified. The emission of formaldehyde (H2CO) shall be below 0.125 mg/m²h. The emission of ammonia (NH3) shall be below 0.06 mg/m²h. The emission of carcinogenic compounds belonging to category 1 of the IARC monographs (IARC 1987) shall be below 0.005 mg/m²h. The material is not significantly odorous (dissatisfaction with odor shall be below 30%). Plasters and tiling products, leveling agents, putty, mastics, fillers, screeds and renders shall not contain casein.

The requirements are based on health and comfort on related experiences of building owners and occupants caused by the building.

The requirements are set to cover as comprehensively as possible, but yet in a practical and cost effective way, the material borne emissions in a building.

Use of the materials to achieve good indoor air quality

The total amount of emissions does not only depend on the emission level of a material, but also the amount of the material or product used in the building. It is therefore possible to small amounts of higher emitting materials as follows:

-Building materials of a space designed according to indoor climate category S1 should predominantly be selected from emission class M1. M2 class building materials should not cover more than 20% of the interior surfaces of a room and never more than 1 m² per m² floor.
-Uncoated brick, stone, ceramic tile, glass and metal surfaces as well as board and log surfaces made of native wood may be used freely. The VOC emissions of fresh wood may exceed the limit value of emission class M1. The use of M3 classified materials shall be limited to the minimum.

-The building materials of a space designed according to indoor climate category S2 should predominantly be selected from emission classes M1 and M2. M3 classified materials should not cover more than 20% of the interior surfaces of a room and never more than 1 m² per m² floor.

-Uncoated brick, stone, ceramic tile, glass and metal surfaces as well as board and log surfaces made of native wood may be used freely.

The materials chosen for a specific structural application shall be chosen according to the manufacturers' specifications to resist the specific condition of the application, e.g., moisture, heat and light. Before installing the materials, they shall be protected from material degrading environments during the storage or building phase.

In the cleaning and maintenance materials low emitting agents shall be used. The manufacturer of the material shall provide directions on cleaning and maintenance agents applicable to the specific material.

References

The Indoor Climate Label http://www.dsic.org/

GEV http://www.emicode.de/

Swedish trade standard for flooring materials http://www.golvbranschen.se/

Classification of Indoor Climate 2000 FiSIAQ. (2001) *Classification of Indoor Climate 2000*. Espoo. Finland: Finnish Society of Indoor Air Quality and Climate, Publication 5 E.

CEN ENV 13419 Building products – Determination of the emission of volatile organic compounds. Part 1. Emission test chamber method

CEN ENV 13419 Building products – Determination of the emission of volatile organic compounds. Part 2. Emission test cell method

CEN ENV 13419 Building products – Determination of the emission of volatile organic compounds. Part 3: Procedure for sampling. storage and preparation of test specimens

draft ISO DIS 16000-6 Indoor air - Determination of volatile organic compounds in indoor and chamber air by active sampling on TENAX TA. thermal desorption and gas-chromatography MSD/FID.

ISO FDIS 16000-3 Indoor air. Part 3: Determination of formaldehyde and other carbonyl compounds – Active sampling method.

5 PROTECTION AGAINST MOISTURE DAMAGE AND MICROBIAL GROWTH

5.1 Rationale and essential requirements

Moisture accumulation into building structures or material may lead to microbial growth on materials, and subsequently to microbial emissions and other contamination of buildings. In epidemiological population studies, moisture damage and microbial growth in buildings have been associated with a number of health effects including respiratory symptoms and diseases and other symptoms, Bornehag et al. (2001). The health effects associated with moisture damage and microbial growth seem to be consistent in different climates and geographical regions. However, the causal agents or cellular mechanisms of the health outcomes are still poorly understood.

It has been shown with relatively good certainty that building-related moisture and microbial growth increases the risk of respiratory symptoms, respiratory infections allergy and asthma. The underlying mechanisms are irritation of mucous membranes, allergic sensitization and non-specific inflammation. Also toxic mechanisms may be involved, especially in connection with toxin producing fungi and bacteria. Certain building materials seem to support the growth of potentially toxic microbes, and even induce toxin production more readily other materials.

While microbial growth and health outcomes are consequences, the common nominators for them are different forms of undesired moisture behavior. Water intrusion, dampness and moisture and related phenomena are not only harmful for the occupants' health but also a serious risk to the condition of the building structures. All these may decrease the indoor air quality of the building. In addition to risks of rot to wooden structures, chemical processes induced by moisture may also deteriorate building materials.

The technical causes of water damage, dampness or moisture control failure are often closely connected to the climate. The prevailing temperature, humidity, rain and wind conditions regulate much of the principles and practices of construction, e.g., foundation, insulation, structure of the building envelope and ventilation system. Indoor humidity is also physically connected to the outdoor climatic conditions. Therefore, the whole issue and problematic of building moisture and dampness, microbial contamination, repair and control practices varies strongly according to the climatic zone. However, regardless of the climate, the prevention and control of moisture problems, and subsequent effects, should be addressed in early phases of building construction practices, and in sustained maintenance of building.

5.2 Moisture control issues in design phase

Moisture calculation methods are available for homogenous structures consisting of porous material layers. One-dimensional calculations are thus easy to carry out as standard design procedure. Some tools allow carrying out more realistic calculations in two or three dimension, but basically accurate modeling of critical construction details and climatic boundary conditions like wind, driving rain and snow is more or less impossible in design. As pointed out in (Samuelson 2002) the real problem is that many of moisture problems cannot be calculated as for instance water leakage in a roof. This may be due bad design, wrong details, bad workmanship or lack of maintenance. Another problem is that materials and structures do not stay clean and dry in the construction phase, as we always have built in wet weather. Often structures do not allow rainwater to dry out before damages occur. Generally, in design, calculations have to be supplemented with other methods. The obvious method is to make a list of all the points that must be checked. Many such checklists are available; one example for cold climate is given by (Samuelson 2002).

In the conceptual design the consultant has to choose the structures for walls, roofs and floors. All these should be checked to be moisture safe both during erection and after a long time of use. The consultant shall take into account the conditions related to building site and to the planned use of the building. He shall also:

- identify the special demands for the building and the indoor environment that have been a basis for the design
- establish instructions and routines for materials and components handling during transportation and building site. The instructions shall include actions if the routines are not followed
- prove moisture safety for the structures by calculations, specifications or other information and point out important details to be checked during erection
- discuss with the owner of the building if he has chosen new, not tested solutions.

5.3 Examples of design strategy to achieve structures with good moisture performance

Design of moisture safe solutions for buildings includes comprehensive analyses of possible sources of moisture, and mechanisms of moisture transfer into and within the structures. Analyses lead to estimation on the consequent moisture loads that the structures and their components are expected to sustain in each stage of construction and during the use of the building. The tasks in the moisture safe design include

- Analysis of effects of moisture in the structures.
- Analysis of the need of technical properties of materials and products. Instructions on how they are verified.
- Design of structures and details. Analysis of their performance and risk characters. Instructions on how the risks can be minimized.
- Estimation of duration of materials and structural components under the presumed loads. Taking into account building tolerances and deformation.
- Design and carrying through quality control measures. For example, how and when moisture content of materials should be measured and what levels should be achieved before coating / finishing; how is the drying of construction moisture ensured.
- Instruction and supervision of careful work performance.
- Instructions on how the building should be used in order to avoid moisture damage.

By estimating ambient temperature, pressure and moisture conditions, and moisture sources, loads and mechanisms of action, buildings can be designed so that under normal conditions, moisture will not cause damage in terms of physical damage (e.g. frost), chemical damage (e.g. corrosion, dissolution or emissions of materials), biological damage (e.g. rot, microbiological emissions) or health risks.

Construction moisture

- Drying as fast as possible should be ensured, by means of ventilating and heating when needed.
- Sufficient time for drying should be provided and assured with careful calculations and measurements.
- Unnecessary wetting of building materials during the storage and construction phases should be avoided.

Air humidity

- Structural design of external envelope should not allow hazardous condensation or long periods of high humidity (>80%) in any part of the structures. If condensation is expected to occur, the excess moisture should be dried away, for example, by ventilation.
- Sufficient thermal insulation should be provided and cold bridges should not cause harm within structures in terms of water accumulation.
- Appropriate use of vapor barriers.
- Increased air humidity should be removed, for example, by ventilation.
- Taking into account the need of ventilation in crawl spaces and external cavities.

Rain, snow and surface water

- Sufficient roof deflection angle, taking into account the type of the roofing material. Details near by eaves, chimney, ducts and other discontinuities on the roofing and external walls need special care.
- Adequate roof drainage and coping systems.
- Sufficient ground deflection angle near by external walls.
- Drainage and under-drainage systems.

Rising damp

- Capillary breaking layers between the ground, foundations and ground floor structures should be employed.
- Thermal behavior and moisture transfer mechanisms of the ground should be taken into account in the design of structures and selection of the materials in contact with the ground.
- Capillary breaking layers between concrete and timber components.
- Non-capillary building materials in contact with standing water.

Liquid water used, water leaks

- Use of water barriers and other moisture protecting components in bathrooms and other facilities with high moisture load and liquid water use.
- Tightness and durability of finishing materials and materials in contact with liquid water and humid air.
- Installations of water- and HVAC systems can be made so that any leakage and/or condensation can be easily observed.

5.4 Moisture control and drying during construction process

The control of moisture and water removal during construction has a decisive effect on attaining the selected indoor climate category. Good construction site planning has a crucial effect on the control of indoor air risks. The control of water, moisture and cleanliness shall be monitored at the construction site. A moisture control plan must be included in the quality control plan of the construction site. A condition for successful moisture control is realistic and enough detailed timetable that allows keeping construction in schedule and makes it possible to follow the issues specified in moisture control plan.

The contractor together with the owner and consultant, shall establish detailed moisture control plan for the building site, erection and drying out phase. All the important checkpoints must be coordinated and it must clearly be pointed out what is and what is not accepted. Test methods, accepted values, tolerances, etc must be clear. The people who have done the work, not supervisors who visit the working place only once a week should fill in the checklists.

In wet climate, the most effective protection against rain is installation of the first layer of roofing and roof drainage down-pipes. This phase of framework needs special attention in scheduling and work planning for achieving as fast as possible progress in roofing work phases. In cold climate, when the frame of the building is closed, effective drying out starts then heat supply is switched on. This is another important milestone in moisture control and its availability shall carefully be scheduled and prepared to keep construction in schedule.

The water and moisture control plan of the construction site shall include the following according to (Lumme and Merikallio1999) and (Samuelson 2002):

- **A checklist concerning moisture risks**. The structures, materials and products that may give rise to moisture problems shall be listed. The supervision at site shall refer to this checklist in order to pay special attention to the details causing most risk. The checklist shall include foundation, framework, thermal insulation, moisture safety and other functions of importance like air tightness, ventilation, etc.
- **Drying out time estimates**. Materials that are coated with moisture sensitive materials must have drying out time estimates for various environmental conditions.
- **Heating, drying, protection and partitioning plan**
- **Alternate plan to keep in schedule.** If the drying out time of the structures is estimated to be longer than the planned schedule permits, procedures to keep in schedule shall be decided on.
- **The handling of materials and equipment.** The transportation of materials to the construction site shall be determined in advance and the reception, intermediate storage, protection and transportation of the materials step by step to their end location shall be planned. The contractor shall make sure that material and components delivered to the building site are correct. All material shall be checked and for especially sensitive materials like wood and wooden materials shall moisture content be measured.
- **Prevention of water damages.** The structures and cavities for thermal insulation must be prevented from becoming wet, for example, from rain or melting water. The work stages of any contractor, which include risks of water damage, shall be determined in advance.
- **Arrangement of drying out conditions.** Good drying out conditions require that the exterior constructions shall be completed as soon as possible, the heating is turned on and the ventilation is sufficient. The moisture control of the

construction may require special procedures which must be agreed on with the HVAC contractor.
- **The organization of moisture control.** The organization of the moisture control of the construction site shall be planned. Everyone involved must be aware and take care of the factors which may cause moisture problems within their own area of responsibilities. The contract agreements shall state the tasks and responsibilities of all parties.
- **Moisture measurement plan**. A moisture measurement plan shall be prepared in advance at the construction site. The plan shall determine the measuring method and equipment, the schedule and scope of the measurements and the location of the necessary measuring points.
- **Coating criteria**. The moisture limits, before which coating is not permitted, shall be defined. The moisture measurement results and criteria for coating are determined for each combination of structure and coating.
- **Documentation**. The moisture control at the construction site, exceptional conditions and water damages shall be documented to an appropriate extent.
- **Information and inspection on construction site.** The checklist shall include time and days of the check as well as the responsible person.

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6 DESIGN AND CONSTRUCTION PROCESS

The quality of indoor climate is affected equally by heating, ventilation and air conditioning equipment, construction engineering, quality of construction work, building materials as well as the operation and maintenance of the building. Good indoor climate requires taking these aspects into consideration during all the stages of the design, construction and use of the building.

6.1 Design phases

6.1.1 Environmental plan

The pre-construction phase includes preparation of an Environmental Plan including:
- Identification of factors with potential influence on the internal and external environments.
- Development of procedures for elimination/minimization of environmental hazards and/or negative impacts.
- Provision/development of the necessary technologies to meet the environmental objectives.

6.1.2 Design brief

This phase should begin as soon as possible after the first discussions concerning inception of the project. The client's objectives should clearly define items and criteria important to the owner, to all members of the design team and to future tenants. These criteria would include:
- Functional use of the facility
- Occupant safety, health and comfort
- Occupancy requirements
- Quality of materials and construction
- Environmental and energy management goals and requirements.

Conceptual designs should be prepared for HVAC systems that will fulfill the basic design requirements. The required functional operation of the HVAC and related life-safety systems should be compiled and set out in the system manual.

Another important action is the appointment of a commissioning manager, who has to start the development of a commissioning plan, and should form a commissioning team with commissioning specialists.

6.1.3 Design

This phase begins with the preparation of the schematic design documents. The documents delivered during the design phase are:
- Performance specification for the HVAC system
- Specification of provisions for maintenance and cleaning
- The commissioning plan
- Description of all building components (HVAC equipment) and systems
- Contract documents that clearly identify, describe and fulfill the design intent.

During this phase, review and accept contract documents for compliance with design intent.

6.2 Construction

The following areas have been identified as having a potential effect on air quality:
- Dust and particulate matter generated during construction/reconstruction
- The quality and design of air handling equipment (Nathanson 1993)

- Maintenance procedures
- Selection of interior building materials and furnishing (design phase)
- Performance of the building protection against influences from soil, e.g. radon.
- Emissions from office equipment, e.g. copy machines.

Implementation of a building project which employs new or innovative techniques requires the total co-operation and participation of sub-contractors:
- Education of contractors
- Displacement of conventional practices and attitudes
- Introduction of the "Clean Building Philosophy"
- Creation of work stations with no objective reasons for complaints of the indoor air quality and climate (IEQ)
- Trying to avoid a number of common problems during the initial design and construction phase.

6.2.1 Example: Clean Building Philosophy

The following specific measures will be implemented for control of dust and other particulates contamination during the construction phase of the project (Flatheim 1993):
- All interior surfaces to be spray-painted to minimize concrete dust and the smell of cement
- All wall penetrations for ductwork, cable runs, etc. sealed to avoid cross-contamination of building areas by dust/particulates
- All carpeting sealed off until dust-producing construction activities is completed
- All ductwork sealed prior to delivery and after installation until immediately prior to start-up
- Accumulating construction dust and debris systematically removed
- All mineral wool insulation materials isolated from any contact with ventilation air (Hedge 1993).

Routine clean-up activities during construction are accomplished by means of a centrally located vacuum cleaner system, which is also used for normal cleaning operations following occupancy in areas with carpets.

The standarized air handling systems (AHS) (Fig. 6:1) has been designed and equipped with a number of innovative features to maximize air quality and worker comfort, such as:
- No recirculation of air is employed to allow for a continuous purging of the building interior with filtered outside air.
- Cross-connections between inlet and outlet ductwork are not allowed to eliminate possible "feedback" of contaminated air.
- Electronic controls provided in each office to allow individual adjustment of air flow.

Accepted criteria for thermal, atmospheric and acoustic indoor environment in office and commercial buildings are shown in Appendix 6. This document should be a specific part of the discussions during the initial part of the design phase (pre-design phase).

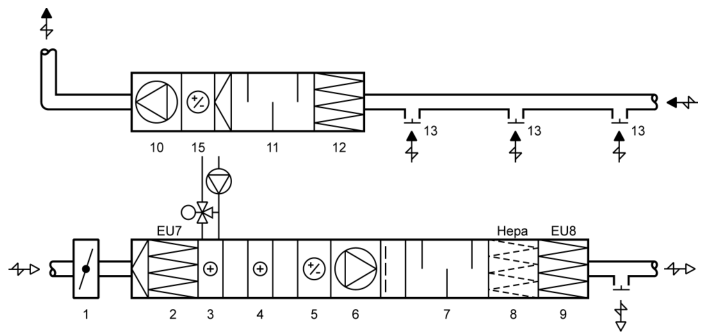

Figure 6:1. Standardized air handling unit for offices and industrial buildings. Damper in the air intake (1), filter EU 7 (2), heat exchanger (3/15), heating coil (hot water (4), cooling coil (5), supply fan (6), sound attenuator (7), and filter after air handling unit EU 7 (9). In some buildings it is necessary to use absorption filter (8). Filter before the extraction air handling unit (12), sound attenuator (11) and extraction fan (10).

Example of training modules needed to build healthy buildings

Each Module covers 4 hours. It is possib le to choose parts of one Module (1-4 hours). The participants will receive a certificate and can choose between Class I (16 hours) or Class II (32 hours).

A. CONSTRUCTION STAGE PERIOD

Module I: The RIGG 2000 – philosophy (clean and dry building)
- the “win-win” principle
- indoor environment
- outdoor environment

Module II: Building codes
- internal control
- documentation

Module III: Health and safety (H & S) culture
- H & S during planning
- H & S during building
- handling of chemicals

Module IV: No complaint buildings
- criteria document
- building codes
- builder’s responsibility
- premises for planning

Module V: Economy and logistic
- potential for the best economy
- criteria for costs
- industrial production
- logistic plan during construction
- delivery procedures (“just-in-time”)
- choise of materials
- shelter from rain and wind
- waste minimizing
- waste sorting

Module VI: Indoor Environment
- criteria documents
- indoor air quality
- contaminations versus health
- user’s evaluation of the environment

Module VII: Life cycle assessments (LCA)
- environment-friendly products
- waste and recycling

Module VIII: Suspended ceilings
- mineral wool (MMMF) – irritations/health problems
- cleaning above suspended ceilings
- hygienic control – metal cassettes
- painting of concrete surfaces

Module IX: Hygiene on site
- Clean Building Philosophy – criteria for clean buildings
- work environment and health
- tidying up/cleaning
- position instructions
- handling of materials
- use of tools

Module X: Phase divided cleaning – procedures
- Phase I: tight building – central vacuum cleaning
- Phase II: after insulation
- Phase III: spring cleaning before move-in

Module XI: Moisture – a dangerous enemy
- moisture and health – seriousness and frequency
- microbial activity
- chemical off-gassing
- drying up of moisture damages

Module XII: Passive fire protection
- fire technical planning and projecting
- regulations and dispensations
- fire technical documentation
- control plans, check lists and documentation

Module XIII: Waste plans for rehabilitation
- codes and reporting
- demolition and recycling
- waste psychology
- special waste
- energy depot

B. AFTER MOVE-IN

Module XIV: Maintenance of technical installations
- heating installations
- ventilation installations
- cooling installations
- automatic controls – regulation

6.3 Design for operation and maintenance

6.3.1 Essential requirements for operation and maintenance

The following design and construction assumptions are made before considering guidelines specific to operations and maintenance;

Building and system design codes have been followed.

In North America these are notably federal, provincial, and state building codes. ASHRAE Handbooks, ASHRAE Standard 62 for ventilation and pollutant control, and ASHRAE Standard 55 for thermal comfort. Building use, equipment, activities, and occupancy numbers are known and included in the design.

The building has been "commissioned", that is, the design performance of the building and systems have been verified. Also, systems have been balanced, and documentation (drawings, design assumptions, equipment specifications, a preventive maintenance program, etc.) is in place.

Pollutant sources have been controlled by material selection, isolation and ventilation. Products with low chemical emission rates should have been selected (environmentally friendly, "green", low VOCs). Dust, particulates, and odors, and off-gassing from new construction materials and furnishings have been monitored and are within normal, acceptable levels before the building is occupied.

The building manager and operator have an adequate budget and the proper tools and training (they are "qualified") to maintain the building and interior environment for health and comfort. Operation and maintenance manuals, cleaning procedures, and schedules have been prepared. They also have an awareness of the issues that influence IAQ; what problems can be resolved using in-house resources, and when expert advice should be sought.

6.3.2 Example of system design and construction features for good building operation and maintenance

The outside air intake should be clear of pollutant sources such as from loading docks, parking areas, trash storage, stagnant water, cooling towers and condensers, exhaust stacks, etc. The intake should be covered by a screen to trap debris and prevent the entry of birds.

The air handling system must be free of debris, friable fiberglass (torn lining), stagnant water, and oily or wet surfaces.
The outdoor air intake must be less than 1.5 m (5 ft) away from terminal, or fan coil units within an open ceiling space.

Separate exhaust systems for kitchens, toilets, printing rooms, labs, etc. should be directed outdoors and must not discharge air within the ceiling plenum or the return air system. Exhaust must not be re-entrained into the building, either through the outdoor air intake or through the building envelope.

Filters should never get wet from rain, snow or humidity. Minimum filtration efficiency should be 30 % for small air handling systems. Larger HVAC system design usually place low-efficiency pre-filters, which are changed several times a year, before high efficiency (> 60 %) final filters. Filters should be positioned after the outdoor and return air mixing plenum, and they should be properly racked for no air by-pass. A pressure drop indicator to indicate when to replace the filters is a good design feature - a gauge is easier to use and calibrate than an inclined manometer.

During construction and refit, the HVAC system should be operated only when filters are in place to protect mechanical components and air supply ducts from contamination.

Access should be provided for inspection and cleaning of all system components, both front and backsides. Finned-tube coils should be no deeper than 8 rows to insure cleanability.

Sensors (temperature, relative humidity, airflow or pressure) should be verified and calibrated according to a schedule. System design can also include sensors for carbon monoxide in parking garages, carbon dioxide for ventilation control, and airflow monitors.

Condensate from cooling coils and water from water-spray humidifiers must be contained (negligible water droplet carryover) and must not wet insulated surfaces or other system components.

The interior surface of condensate pans and reservoirs must be smooth, non-porous, and rust-free to facilitate cleaning and eliminate the potential for microbial contamination. Pans and reservoirs must be sloped towards a drain situated at the lowest point to avoid stagnant water.

Drains within the mechanical system should have traps having a depth and height differential between inlet and outlet 40 % greater than the fan design static pressure to allow for complete pan drainage with fans on or off. A water seal should be maintained to avoid the entry of sewer gas.

Steam humidifiers require less maintenance than water-spray systems. However, steam from a water-heating boiler should not be used directly in the supply air stream, as it will contain chemicals not intended for the occupied space. Boiler steam can be used in a steam-to-steam converter or use potable water with a dedicated steam generator. Humidification systems using atomizers and foggers must use treated water to ensure mineral-free droplets.

Systems designed to circulate water from an open storage tank, reservoir, or sump should have a continuous water bleed or automatic controls to periodically drain the sump to reduce mineral and microbial levels. Water mineral concentration (dissolved solids), measured using a conductivity meter, should normally be no more than 3 – 5 times that of potable water.

Fan performance should provide between 4 to 10 air changes per hour (around one air change per hour of outdoor air). This is equivalent to a supply air circulation of approximately 4 liters per second per square meter of floor space (0.8 cubic feet per minute per square foot).

Ventilation must be provided during occupied hours and may lead or lag the work period to dilute interior pollutants and flush-out the building. Establish the hours of operation of the mechanical system so that at the start of the day, the IAQ (notably CO_2 levels) is near to outdoor conditions.

The building should be designed to operate under a slight positive pressure; typically between 6.25 to 12.5 Pa (0.025 to 0.05 in. wg). This will provide for controlled air exfiltration through the building envelope, rather than uncontrolled infiltration (resulting in thermal discomfort and the entry of pollutants).

Condensation on interior cold surfaces (thermal bridges) or within a wall cavity must be avoided to reduce the potential for microbial growth and material or structural damage. Design the structure with proper insulation, an integral vapor barrier, sealed window frames, and controlled airflow and humidity to avoid this situation. Cold surfaces such as cooling supply ductwork, chilled water supply and return piping, fan coil and induction unit condensate pans, etc. should be insulated on the outside to prevent condensation. Components that are difficult to insulate such as valves, regulators, etc. should have pans placed under them

6.3.3 Example of design and construction for good IAQ within the occupied space

Each closed office should have a supply air diffuser.

Supply air should not short-circuit the office space and flow into returns.

Air supply ducts should be insulated externally rather than internally to prevent loose fibers from becoming airborne, to facilitate cleaning, and to avoid the potential for microbial growth. Limit the length of flexible connector ducts to reduce dust build-up.

Air leakage from ducts should not exceed 10 % of supply volume. Access doors and hatches must be sealed with gaskets.
As it is usual for the space above the ceiling tiles to serve as the return air plenum, damaged, soiled, or missing tiles should be replaced. The entire ceiling space should provide a clear pathway for return airflow and offices with walls from floor to ceiling (slab) should have transfer ducts installed. There should be no loose fiberglass batts within the ceiling; for acoustic insulation it is best to improve the performance of the ceiling tile (use rigid tiles).

While there is no minimum air speed that is necessary for thermal comfort, air movement can offset increased temperature. An air speed range of between 0.05 and 0.15 m/s (10 – 30 fpm), is recommended at desk level. For sedentary occupants, drafts should be avoided.

The vertical temperature difference from foot to head should not exceed 3 °C (5 °F). The surface temperature of the office floor should be between 18 and 29 °C (65 – 84 °F). Cantilevered floors should be properly insulated.

Pollutant source control is the most cost-effective strategy for good IAQ. Strong, indoor generation sources producing VOCs, odors, heat, or particulates should be isolated and exhausted directly outdoors (local or dedicated exhaust). Ventilation simply dilutes the pollutant and distributes it to the rest of the building.

Control airflow (air pressure) from clean to less-clean areas. Air from an office area or hallway should flow into a laboratory, washroom, garage, etc. not the other way around. Airflow control is achieved through system balance.

A variable air volume (VAV) terminal must not throttle the supply air below a specified volume to insure that the minimum ventilation rate is maintained at each workstation throughout the occupied period.

Access to perimeter convection, induction or fan-coil units must be provided. Furniture should not be placed against the units, and the air supply grates and airflow should not be blocked. The units should not be wedged between walls or columns such that removal is difficult.

Induction or fan-coil condensate pans must not contain stagnant water; evaporation or drainage must be assured daily. The pan interior should be easy to clean, and must not be insulated with porous material such as fiberglass or foam.

In an open office concept, air circulation improves as the design height of privacy screens or partitions is lowered; the optimum height being 1.5 m (5 ft). Providing an open space or gap under the screens does not effectively improve air circulation. Office areas under 10 m^2 (100 ft^2) should not be created.

To reduce thermal load and facilitate air balancing to ensure uniform thermal conditions, exposed windows should use reflective glass or be shaded by overhangs, blinds, or screens.

6.4 Commissioning of HVAC system

The commissioning relies on the design documentation described in chapter 6.1. The commissioning process begins with the appointment of a commissioning manager. The manager has to start the development of a commissioning plan, and should form a commissioning team with commissioning specialists.

During the design phase, the commissioning manager should review and accept contract documents for compliance with design intent.

6.4.1 Pre-commissioning

In this phase all the necessary preparations are made for the construction commissioning. There should be a maximum of pre-commissioning of equipment and software, which should take place off-site wherever possible. Commissioning records are filled out and held on file.

6.4.2 Construction commissioning

During this phase of the commissioning process, the HVAC system is installed, started and put into operation.

The HVAC equipment is checked, together with system start-up and operation.

The achievement of design comfort temperature is checked, also the performance of building management controls and energy consumption.

Testing, regulation and balancing work is carried out. Components and systems are tested and certified ready for commissioning. All responsibilities and schedules for functional performance testing are determined. Field inspections are undertaken regularly to assure that the construction complies with the documentation, which includes:

- Updated commissioning plan
- Updated descriptions of all building components, equipment and systems
- Field inspection reports
- Pre-functional performance tests.

Example of of a commissioning checklist (Flatheim 1993).

When the installations are completed, the following should be compared with the contract:

- Are flow rates (outside air) in accordance with the criteria document
- Has data logging been used to ensure that the room temperatures are in accordance with the criteria document?
- Are draught limits and sound levels in accordance with the criteria document? Check all components in the HVAC system (Fig. 6:1):
- Is the damper (1) in the air intake properly installed?
- Is the bag filter (2) according to contract?
- Is the energy conservation system (3/15) in function and the heat recovery efficiency according to specifications?
- Is the heating coil (4) properly installed and without damage?
- Is the cooling coil (5) properly installed and free of damages?
- Are the fans (6/10) properly installed and the belts correctly chosen?
- Are the sound attenuators (7/11) without damages (missing insulation)?
- Are the bag filters (9/12) properly installed and class EU 9?
- Is the cooling machinery correctly installed and the capacity according to the contract?
- Have you checked the direction of the air motion:
    - between offices and wardrobes/WC-rooms?
    - between offices and elevators. staircases and the garage?
    - between offices and rooms for copying machines and printers?

6.4.3 Acceptance commissioning

Functional performance tests have to be carried out during the acceptance phase, and a procedure for their verification by owner and/or consultant has to be agreed on. This is the core of the commissioning process, with the following aims:

- Verify the accuracy of the final testing, adjusting and balancing report
- Verify that the HVAC system complies with the contract documents
- Establish an as-built record of the HVAC system performance
- Complete the commissioning documentation
- Complete the project handbook.

To be accepted, the following shall be observed and documented:

- HVAC airside and waterside systems and associated subsystems have been completed, calibrated, tested and started up
- automatic control systems have been completed and calibrated.

6.4.4 Post acceptance

This phase covers the continued adjustment, optimization and modification of the HVAC system to meet specified requirements. The objective is to maintain the performance of the HVAC system throughout all seasons and over the full useful life of the facility. Performance should be in accordance with the current design intent, which may have changed since handover. Documents produced during the post-acceptance phase include:

- Periodic update of as-built drawings
- Periodic updates of operations and maintenance manuals
- Log of user feedback and complaints, plus any occupancy questionnaire survey
- Record of environment and energy performance as a function of time.

References

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The RIGG 2000 – philosophy

7 OPERATION AND MAINTENANCE

7.1 Rationale and essential requirements

Building and systems design and construction specifications must incorporate procedures for proper operation and maintenance to provide not only a safe and healthy workplace, but also a comfortable and productive one.

Proper operation and maintenance of a building and the mechanical heating, ventilating and air-conditioning (HVAC) system is a critical requirement for the provision of good IAQ. Large scale surveys of buildings with sick building syndrome (SBS) made by the US NIOSH and the Public Works Canada have indicated that in over 50% of the cases, the problems can be attributed to improper building design, operation, and maintenance.

Policies and programs should be developed with regard to:

- Cleaning (materials, time, and frequency)
- occupant complaint log and response
- refit and renovation activities
- accommodating persons with environmental sensitivities.
- communication for catastrophic events (flood, power failure, etc.)
- IAQ program of audits, quality assurance, and investigations, and
- where and when to obtain expert advice.

Liability for poor IAQ begins at the design stage and continues throughout the life of the building. Pro-active management and proper operation and maintenance will prevent problems and demonstrate “due diligence”. Economies can be realized as prevention is less costly than remediation, legal claims can be reduced, and issues regarding leasing and holding of tenants will be minimized.

Proper operations and maintenance of the building and systems can effectively continue to provide good IAQ and will demonstrate that the building owner and facility manager have diligently applied good engineering practice for the safety, health, and comfort of occupants.

7.2 Preventive maintenance program

Maintenance consists of measures for preservation and repair as well as for the statement and evaluation of the actual condition of technical systems. Contained in these measures are servicing (measures for system maintenance “as designed” of technical systems. Maintaining the prescribed condition). inspection (definition and evaluation of the actual condition of technical systems. Identification and assessment of the actual condition) and repair. Maintenance should be performed as a preventive measure. In detail one can entitle a preventive measure the first of the 3 actions in table 7.1.

Table 7:1.Definition of Maintenance according to DIN 31 051.

Maintenance		
Grouping of measures		
Servicing	Inspection	Repair
Aims of measures = definition according to DIN 31 051		
Maintaining the prescribed condition	Identification and assessment of the actual condition	Restoration of the prescribed condition
Individual measures		
Testing Readjustment Replacement Supplementation Lubrication Preservation Cleaning	Testing Measurement Assessment	Repair Replacement
Carried out by		
Skilled mechanic Technician	Technician Engineer	Skilled mechanic Technician

Its aim is maintaining prescribed conditions. The conditions are given by mechanical and hygienic requirements. The work consists of testing, readjustment, replacement, supplementation, lubrication, preservation and cleaning. It has to be performed by a skilled mechanic technician.

A prerequisite are the prescribed conditions. Additionally a time schedule is necessary. Proposals especially from the hygienic position are given in the Appendix 7. The intervals given in the following tabular checklist are general empirical values from a technical and hygiene point of view. Shorter intervals may be necessary in actual individual cases.

An example of maintenance inspection checklist (Flatheim 1993)

After move-in qualified personnel should inspect and maintain the building and technical installations regularly:

- Control of building (leakages), cleaning, damages and function during a walk-through
- Possible IEQ complaints should be taken very seriously. Such complaints could be linked to improper operation and maintenance and unsatisfactory cleaning procedures.
- The facilities staff should be able to keep control by monitoring.
- An alternative is to establish a contract with a qualified HVAC company taking into account interrelationship between lightning, acoustics and ergonomics and understanding the functional and operating requirements of all components.
- Compare that capacities (spots tests) with the criteria document twice a year.
- Control that the filter banks are dry and clean. Do not use the manufacturer's pressure drop (resistance) rating.
- Ensure that air ducts and space above suspended ceilings are maintained and cleaned to prevent dust from entering (falling down to) the office space.
- Verify the existence of a proper maintenance schedule for ceiling air handling units (AHU's), controls and thermostats.
- Provide a system for regular cleaning and preventive maintenance of air intake grids and dampers, filter banks, tubes, heating/cooling coils, fans and sound attenuators.
- Prevent stagnant water in air handling units and in cooling systems and remove corrosion continuously.
- Follow the ASHRAE Guideline 1-1996. Chapter 37.

References

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8 LIST OF APPENDIXES

Appendix 1: Ventilation efficiency

Appendix 2: Measuring methods for material emissions

Appendix 3: Measurements of moisture contents of materials at construction site

Appendix 4: Verification and measuring methods for cleanliness of HVAC system

Appendix 5: The optimal operation conditions of filters in the HVAC system

Appendix 6: Examples of criteria for thermal, atmospheric and acoustic indoor environment – office buildings

Appendix 7: Checklist for the hygienic operation and maintenance of air-conditioning systems (according to VDI 6022)

Appendix 1: Ventilation efficiency

The efficiency could be related to how efficient contaminants are removed from the zone of occupancy or how efficient the fresh air is distributed in the room. There are several ways of defining the efficiency; the two most applicable are the Contaminant removal effectiveness and the Air change efficiency.

Elimination (local exhaust) of contaminants close to the source gives the best ventilation effectiveness (High contaminant removal effectiveness) while an ideal piston flow where ventilation air moves uniformly gives the best exchange of air (High air change efficiency).

A piston flow is seldom practically applicable so for most purposes displacement ventilation gives the best obtainable air exchange efficiency.

Table 1. Effectiveness of different types of ventilation

		Displacement	Complete mixing	(Short sircuit)
Contamination removal	Contaminant removal effectiveness	1-∞	1	0
Air distribution	Air exchange efficiency complete room	1-0.5	0.5	0-0.5

General advice:

- Short circuit must be avoided, i.e. fresh air must be prevented from flowing directly from the supply to the exhaust without ventilating the zone of occupancy.
- Ventilation used for space heating with high wall mounted exhaust grilles should not be used.
- Contaminants should either be effectively diluted (complete mixing) or the overall ventilation airflow pattern and the contaminants should naturally move in the same direction (displacement ventilation)
- Displacement ventilation only gives better efficiency than complete mixing provided that sufficient airflow rates are used.
- Short circuit outside the room also deteriorates the air quality.

Appendix 2: Measuring methods for material emissions

Material emission testing consists of the following phases, all of which are equally important in striving to a reliable emission value:
1.-sampling of the material or product from the production line,
2.-packaging the sample, transport and storage before testing,
3.-test specimen preparation
4.-conditioning (ageing) of the test specimen,
5.-use of the emission test chambers
6.-air sampling from the test chamber (chamber techniques),
7.-analytical methods to characterise the emissions,
8.-reporting the emission results the required by a specific labeling or classification system

Today there exist the standard /CEN ENV 13419/ Parts 1-3 covering the phases 1-5. However, as there exist many different types of building materials and products, this standard does not today cover all the groups, and therefore the national labeling and classification systems give more detailed instructions to be followed for each national label application (GEV, Swedish trade standards and the Danish-Norwegian labeling, the Finnish classification)

The chemical analysis of VOC- emissions and indoor air quality is established in ISO ISO/TC 146/SC 6/WG 3, and exists today as an ISO DIS 16000-6 draft. The national labeling systems have own requirements for VOC-measurements and reporting (GEV, Swedish trade standards and the Danish-Norwegian labeling and Testing protocol for the Finnish Classification

For analysis of formadehyde (and other aldehydes) from indoor air, there exists the standard ISO/FDIS 16000-3. This standard gives a method which can also be used in emission determination from test chambers. (see also GEV, Swedish trade standards and the Danish-Norwegian labeling and Testing protocol for the Finnish Classification).

Ammonia is absorbed into dilute sulphuric acid and analysed with an electrode specific to ammonia or by a spectrometric method (Testing protocol for the Finnish Classification).

The sensory evaluation of material emissions used in the Finnish classification is described in the testing protocol.(Sensory testing protocol for the Finnish Classification). The sensory testing by an untrained panel consisting of five to ten members using an acceptability scale from –1,0 to +1,0.

References

CEN ENV 13419 Building products – Determination of the emission of volatile organic compounds. Part 1. Emission test chamber method.

CEN ENV 13419 Building products – Determination of the emission of volatile organic compounds. Part 2. Emission test cell method.

CEN ENV 13419 Building products – Determination of the emission of volatile organic compounds. Part 3. Procedure for sampling. storage and preparation of test specimens

draft ISO DIS 16000-6 Indoor air - Determination of volatile organic compounds in indoor and chamber air by active sampling on TENAX TA. thermal desorption and gas-chromatography MSD/FID.

ISO FDIS 16000-3 Indoor air. Part 3: Determination of formaldehyde and other carbonyl compounds – Active sampling method.

Appendix 3: Measurements of moisture contents of materials at construction site

When conducting an IAQ investigation it is often necessary to use several different kinds of moisture measuring methods. The relative humidity and temperature are measured in the room air, in the support air, outdoors and inside structures and building materials. The moisture content MC (kg/kg) is measured in wood at the investigation site or samples of wood or other hygroscopic materials are brought to a laboratory for analyses. Indicating moisture content is done with different kinds of moisture indicators on the surface of the floor, the roof or the walls to check out where the moisture content is high.

In all cases it is important to use calibrated instruments and to know what you are measuring and what the normal values are. Normal values are depending on the time of year. In cold climates there is a big difference between the moisture content in the air at different times of the year. The MC is even depending on the temperature why it differs widely in materials close to the outdoor air over the year. That means that the MC at equilibrium differs a lot between winter and summer both indoors and outdoors. In porous or thin materials the MC follows the Relative humidity (RH) in the air quite well but inside a concrete slab it is quite stable over the year.

To find moisture damage and moisture sources you must know if the result of the moisture measuring you does is normal for the time of year or not. Even normal values can exceed critical moisture levels. The MC in a wooden roof over a cold attic or a wooden facing outside an external wall can easily be more than 15% during the winter. That means risk for mould growth — if the temperature hadn't been so low.

Field measurements

In some materials (wood, chipboard) it is possible to measure the MC. Note that the MC can be higher than 100% if the weight of the water in the material is higher than the weight of the dry material. Normally the instruments are designed for pure wood (pine or spruce) but practical experiences show that you come close to the truth even in chipboard.

Figure 1. Two nails are pushed in to the wood. The nails are connected to the instrument by a cable. It is possible to use loose nails if it is too tight where you are going to measure. The electrical power gives a higher reading on the display if the moisture content is high. The same method can be used in other porous materials to indicate where the moisture content is high.

Figure 2. In this case water from the ground has passed through the concrete slab up to the wooden sill laying on top of the concrete without any moisture barrier between. The reading is close to the fibre saturation point in pine (28%).

Laboratory measurements

A piece of the material (size like a matchbox) is cut out and placed in a vapour tight plastic bag carefully tightened and put in another airtight plastic bag even carefully tightened. The sample has to be marked with a sample number and place of sampling.

In the laboratory the sample is taken out from the plastic bags and weighted carefully. After that the sample is placed in an oven at 60°C and is kept there for at least four days or until there is no weight loss in the sample. The temperature shall not be as high as 70°C to avoid that other components than water are vapourised.

After the four days in oven the sample is weighted again. The weight loss divide by the dry weight is the MC.

Capillary saturation degree

When pouring a concrete slab the vibrating of the concrete make heavier particles, like stones, sink downwards. That results often in that the concrete is heavier and is less porous in the bottom of the slab than it is near the upper surface. Determining the MC at different depths to investigate the moisture transportation direction in that case result in a higher MC in the upper part of the concrete due to lighter concrete, not due to more water. Comparing the MC:s in such cases can give the wrong answer.

To avoid that kind of mistakes is it better to determine the capillary saturation degree (CSD). At RH below 90% it is enough to compare the RH at different levels in the slab but when RH is higher it is necessary to compare the CSD at different levels.

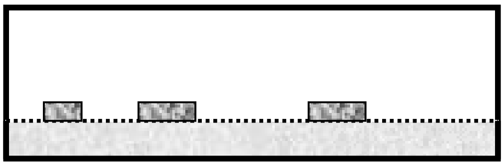

Figure 3. The samples are taken at the different depths. Sample size about the size of a matchbox.

Each sample is placed in a vapour tight plastic bag carefully tightened and put in another airtight plastic bag even carefully tightened. The sample has to be marked with a sample number and place of sampling.

Figure 4. In the laboratory the sample is taken out from the plastic bags and weighted carefully. The samples are placed in a tight box made of transparent plastic or glass on a metal net just in contact with water

The samples are kept in the box for 3-4 days until it is capillary saturated. After that the samples are taken out of the box, free water on the bottom surface of the samples is carefully taken away and the samples are weighted again.

The next step is to place the samples in an oven at 105°C and keep it there for at least four days or until there is no weight loss in the sample. The temperature shall not be higher to avoid that other components than the free water are vapourised.

After the four days in oven the sample is weighted again.

Now we have the dry weight (A), the original weight of the sample (B) and the weight of the capillary saturated sample (C). We calculate the original MC in the sample and the MC when capillary saturated and divide the original MC by the MC in the capillary saturated sample. The result is the capillary saturation degree.

$$CSD = \frac{\dfrac{B-A}{A}}{\dfrac{C-A}{A}}$$

The CSD:s at different levels can be compared and the moisture source is most likely to be found in the direction where the highest CSD is found.

Indicating moisture

There are many different equipments named moisture meters in the market. To measure it is necessary to penetrate the material. A more true name is often moisture indicators for the instruments you just hold on the material surface. Those are very useful instruments if you know their limitations. It is not possible to translate the reading to any value of RH, moisture ratio or MC.

Placed on a material surface a reading is shown on the display, different high depending on moisture content in the material but also depending on kind of materials in and below the surface. It is normally impossible to translate the reading to any moisture value but if completed with measurings it is possible to become a good picture over the moisture content in different parts of the same construction. Do not compare readings on different flooring materials and do not use this indicator when measuring moisture if a particular moisture level is important (RH_{crit}).

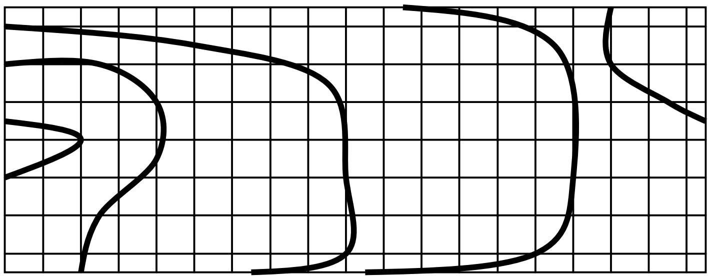

Figure 5. Scanning on floors searching for high readings often give a good picture over the differences in moisture content in different parts of the floor. Indicating at every 500 mm over the floor make it possible to do a drawing telling where to measure and sometimes the possible reason to the high moisture content. High readings close to a bathroom wall indicate leakage from that direction.

Relative humidity, RH (%)

Measuring in the air is done with RH instruments in the house (or outside it) while measurements in material pores can be done either in the house or in a laboratory. Laboratory analyses are always to prefer due to many difficulties when measuring in the field.

Measuring in the air

Depending on the purpose of the measuring it can be done during a short or during a long time. The short time measurings are normally made with hand held instruments showing the actual RH and temperature on a display or with some kind of psycrometer. This kind of measuring gives quite a rough picture of the RH and it takes much experience to right value the result. Are the sensors calibrated close to the actual RH level, are the conditions indoors and outdoors representative? Long time measurings can be done with instruments collecting data during the measuring period, data that you can collect from the instrument in to your computer and show as diagrams. Those measurings give a more true picture of the RH and temperature over the period. When the outdoor RH and temperature are measured you can calculate the moisture content in the air. The reading (X % RH and Y°C) give a moisture content (g/m^3) of X % of the vapour concentration at saturation point at Y°C.

The moisture content in the indoor air is compared with the moisture content in the outdoor air. With a proper working ventilation system (0.5 ac per h) the indoor air will contain 1-3 g more moisture per m^3 than the outdoor air. Even moisture contents in inbuilt spaces under floors, in attics or in walls can be evaluated in the same way.

Measuring in materials

Measuring in materials show the RH and temperature in the air filled pores inside the material. The RH inside a hygroscopic material is depending on the moisture content (liquid water) inside the pores in the material. RH inside a material doesn't vary with the temperature in the same way as RH does in the air in a room. When the temperature rise in a material some of the liquid water vapourise and the vapour concentration rise but the RH remains about the same except from that the sorption curves are depending on the temperature. In the air in a room there is not enough liquid water available and when the temperature rise the RH drops.

In drilled holes

Measuring can be done in drilled holes. The measuring can not be done soon after the drilling depending on that the drilling has changed the temperature in the material.

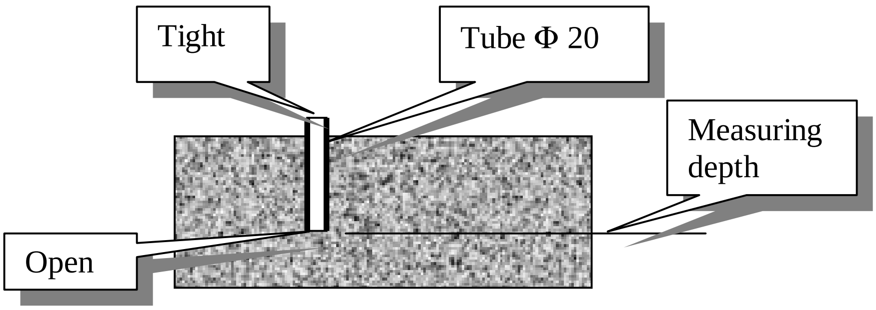

Figure 6. In concrete you can drill a hole Φ 20 mm down to the level of interest and seal it inside with a plastic tube open in the bottom or with equipment delivered together with some RH instruments. The measuring can be done one week after the drilling and preparation of the hole is done.

After adapting the sensor in the tube and carefully tightened it again in the top you have to wait until the conditions inside the tube are in equilibrium with the conditions in the concrete at the measuring level. It can take several days depending on the moisture capacity in the sensor and its filter! One way to shorten that period is to prepare the sensor in an RH climate close to that you expect it to be in the tube. If you suspect that the RH is around 90% in the concrete you can keep your sensor in a calibration box with bariumcloride (90% RH) just before adapting it in the tube. If it is winter time in a country with a cold climate the RH indoors can be very low. A sensor kept in that climate will adsorb much of the vapour in the tube (dry it out) and it takes several days before equilibrium occur again. This is based on practical experience from many measurings. If you are following the drying out process in concrete a better, but more expensive, method is to keep the sensor in the tube all the time until the concrete is dry enough. This method is normally difficult on a building site due to risk of destruction of the equipment. Today there are some methods available making it possible to keep equipment hidden during construction time.

In a laboratory

A more reliable method to measure the RH in a material is to do analyses on samples in a laboratory.

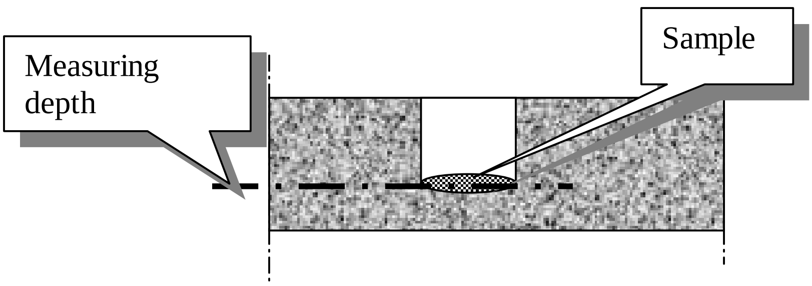

Figure 7. The sample has to be taken out as close as possible to the depth you are interested in.

Drill (without water cooling!) a hole Φ 100 mm down to 5 mm below the measuring depth, take away the concrete plug and cut out pieces of concrete, by hand, from the middle area of the bottom of the hole. Avoid pieces close to the sides as this area is quite warm due to the drilling. The sample may contain pieces from 10 mm over and 5 mm under the measuring depth. Put the pieces of concrete in a measuring box or in a tight plastic bag without any delay, the piece has to be put in the box or the bag as soon as it is cut loose to avoid drying out. Mark the sample bag and put it in one more tight plastic bag. Deliver the samples to the laboratory without any delay, at latest the day after the sampling was done.

Figure 8. It is important to keep a constant temperature in the samples during measuring. On the picture you can see a thermal insulated box containing six measuring boxes.

The pieces of concrete are kept in the measuring box of glass sealed with a rubber cork until it arrives to the laboratory. In the laboratory the rubber cork is replaced by the RH sensor and the box is put down in one of the holes in the insulated box. The measuring continues for at least three days to be sure that the real RH will be registered. The measurings are stored in a computer and can be shown either as diagrams or as figures.

Appendix 4: Verification and measuring methods for cleanliness of HVAC system

Inspection of functionality and cleanliness of HVAC system is a part of proper maintenance of the ventilation systems. The methods to verify cleanliness are diverse and no standardisation has been done even in national level, to say nothing of international harmonisation. Besides the maintenance personnel, objective methods to verify cleanliness of the air handling unit and ductwork are needed by building owners, landlords and air duct cleaners. Mostly the inspection of the cleanliness may arose from two purposes:

- to check if HVAC system is dirty and need to be cleaned (exceeding of a "trigger" level)
- to evaluate cleanliness after the cleaning work (effectiveness of cleaning)

In the first case the verification methods needs to be consistent that both landlords and tenants may accept the result of the inspection and the result of inspection gives reliable grounds for decision making to order cleaning work of the system. In the second case, the verification methods are needed by cleaning company for quality control of their work, and also by the building owner as a customer to verify the cleaning result.

Objective methods are also needed if any guidelines or demands on cleanliness are set in official or in voluntary documents. According to an international workshop held in HB2000 conference official or voluntary guidelines have been set in many countries. For example, the Finnish Indoor Climate Classification 2000 gives cleanliness values for old existing systems and also for recently installed duct works. However, the methods to evaluate the cleanliness vary, and thus trigger values given for the cleaning action is not easy to compare. The workshop was unanimously in agreement that visible microbial growth or bird droppings are not allowed in the HVAC system, but it was much harder to reach a common understanding on the needed cleanliness level for the HVAC systems if the dust is only inorganic in origin. The question is especially difficult to answer when buildings used for different purposes (e.g. offices, schools, and hospitals) are taken under discussion.

Research work on cleanliness of HVAC systems is going on in many countries, which also promotes the development of the evaluation methods.

Evaluation methods

Visual inspection is a basic method to evaluate the cleanliness of HVAC system. Although it is objective as such it gives a very good estimate of the condition on ventilation system surfaces. It is usually good enough to detect e.g. microbial growth on water reservoirs, and deposits from major malfunction of filtration. The visual inspection may be assisted with technical devices such as cameras, endoscopes, and robotic cameras with video footages. In some references, the visual inspection is developed more repeatable by using special forms and notebooks which make the inspection more systematic (Lovoie and Lazure 1994, HVCA 1998). For example in a Canadian guide purposed to prevention of microbial growth in ventilation systems, the checklist contains components from outdoor air intakes, different sites in AHU, both supply and exhaust air ducts with peripheral units. The cleanliness is classified in a scale from 1 to 4 in which 1 refers to very clean and 4 means some stage of reduction in air flow (Lavoie and Lazure 1994). To make visual inspection more objective, besides the list with dirtiness scales the inspectors should have experience from many HVAC systems. Visual inspection need not to refer any mass values, preferably objective of the inspection (with the aid of scale) should be the need of cleaning and other action for repairs. In clear cases visual inspection by a trained person is also a useful method to evaluate cleanliness after the cleaning.

Methods for deposited solid dust

Most of the methods to verify cleanliness of ventilation systems are based on the measure of mass of the dust and debris deposited on a known surface area. In the **filter sampling method** dust vacuumed on a filter is weighed either without filter housing, or it can be weighed together with the housing. In the latter method, the dust fastened on the walls of the filter housing is easily counted to the sample. Several methods are developed for to loose the dust from the surface. The dust may be loosened with aid of a metal blade (Nielsen et al. 1990) which may take also some metallic zinc particles from rough surfaces (Fransson et. al. 1995). Although soft plastic scrapers are not so effective for the tightly fastened dust, they are recommended because they leave the metal surface untouched (Pasanen 1998). Mouthpiece of a filter cassette is also used of loosening of the dust from an area rejected with a 100 cm^2 flexible template. In one standardised method the dust is loosened by air stream in a narrow slit between template and filter holder. The method takes effectively the loose particles to the sample (NADCA, 1992), and thus the result of the method describes more the amount of potential particles that can be driven to air stream than the total dust deposition if the dust is tightly fastened on the surface. This method is developed to verify the cleanliness after the cleaning.

The sample is also possible to take without vacuuming by **wiping method** on the filter or filter-like cloth (Ito et al. 1996, Kumagai et al 1997). Solvent may strengthen the loosening of the dust from the surface, which make the method very effective especially for greasy solids (Fitzner et al 1999, Muller et al. 1999).

A sticky tape is also used to collect deposited dust particles from the surface (Fransson et al. 1995, Holopainen et al. 2001). The tape is weighed before and after collection of the dust and the difference of the mass is used in calculation of the dust density on the surface. The shape and dimensions of the tape restricts the sampling area constant. The method is rapid if the balance is used in the field. According to preliminary studies with different tapes the moisture and hygroscopicity of the tape material affects the reliability of the method. On very dusty surfaces, the collection capacity of tape on surfaces with dusty surfaces rejects also the usefulness of the method to obtain objective value. However tests on the surface with recently deposited dust revealed that the recovery is good from surfaces with dust accumulation level less than 4 g/m^2 (Pasanen 1999).

Sampling site and size of the area is selected and determined variously in different studies. The standard method by NADCA determines a constant 100 cm^2 area and the distance from the surface is determined with thickness (1 mm) of the template. In most studies the sample is collected from the duct bottom which is well argued especially in rectangular ducts because most of the accumulation occurs to the bottom surface of the duct. In circular air ducts, the definition of the bottom is not so clear, and therefore, the diameter of the duct affects the broadness of the accumulation area. In Finnish studies (Pasanen et al. 1992, Lahtivuori 1996, Pasanen 1998), the sample area is determined so that a quarter sector from lowest to widest line of the duct is chosen as the boundary lines for the sampling area. This means that different sizes of templates are needed for different duct diameters.

A gel tape method (Schneider et al. 1996) is developed for verification of the cleanliness of indoor surfaces. The sample is collected on a transparent tape that contains gelatine gel as glue. The transparency of the tape is measured with a special analyser, BM Dust Detector, before and after the sampling. The analyser gives a percentage value (%) which is related to the density of dust particles on the gel surface. The composition of the particles and fastening of the dust on the surface affects the readings increasing the variation in the results (Holopainen et al. 2001). This is avoided by taking several samples from the same sampling point.

A British guideline is partly based on the deposit thickness test (HVCA 1998). The thickness of dust layer is measured with the aid of a special device. The measuring procedure applies an instrument that bases on electromagnetic induction sensor. At the first, at least 20 background thickness readings are taken from randomly selected sampling area. After that the area is carefully cleaned and the measurement is repeated. The differences in these two readings give the mean thickness value.

Comparison of the methods

Loosening efficiencies of the evaluation methods varies a lot (Table 1) (Fransson et al. 1995, Fransson 1996, Fitzner et al. 1999, Holopainen et al. 2001). The collection recoveries (efficiencies) have been determined only for cloth wiping and NADCA standard methods. For the cloth wiping method, average recoveries of dust varied from 87% to 95% (Ito et al. 1996). The recoveries of the methods depend on the surface to be sampled. Those of the NADCA method tested using typical surfaces present on HVAC systems was 70% on galvanised sheet metal, 40% on duct liner, and 16% on fibre board surfaces (Anon 1995). Fitzner et al. (1999) have determined efficiency factors by comparing the other methods based on vacuuming technique to their cloth wiping method with solvent (Table 1). The use of propanol as a solvent strengthened the efficiency of the collection of the cloth even higher than scraping with a blade which was ranked as the most efficient method in Fransson et al. (1995) study.

Table 1: Relative efficiencies of the sampling methods developed for the solid deposits in the HVAC systems (Fitzner et al. 1999).

Method	Standard or note	Efficiency of the method
Wiping with cloth	solvent	1
Filter with vacuum	scraping with blade	0.9
Wiping with cloth	JADCA	0.5
Tape	gravimetric	0.35
Filter with vacuum	with brush	0.15
Filter with vacuum	scraping with filter holder	0.1
Filter with vacuum	NADCA / HVCA	0.02

The performance of dust collection of gel tape for optical method, gravimetrical dust tape and filter methods have been compared at laboratory conditions with dust collected from used ventilation filters. In a used dust density range of 0.3-15 g/m^2, the gravimetrical methods have given equal results in the range of 0.3-4 g/m^2. Above that range the dust tape did not have capacity enough to take all the dust from the surface. Similarly the result of the gel tape method showed that the method gives quite linear relationships between the dust density if the dust density do not exceed 4 g/m^2. Thus, the tape methods used for dust collection are applicable in purposes where the amount of dust is low or the method is used only for detection if the amount of dust exceeds the set trigger value (Pasanen 1999).

Methods for sampling microbial contaminants

Microorganisms are ubiquitous and will grow wherever environmental circumstances are suitable. HVAC systems with relatively high air humidity, accumulated moisture, adequate substrates, such as dust or decayed insulation with organic debris, and suitable temperature provide a favourable environment for microbial growth. Case reports and studies have shown that microbial contamination by fungi and bacteria is common in water reservoirs, e.g., cooling towers, humidifiers (e.g. Ager and Tickner 1983), drain pans, traps and sumps (Morey and Williams 1991), cooling coils (e.g. Byrd 1996), heat exchangers, and thermal or acoustic insulation (e.g. Bernstein et al. 1983, Morey and Williams 1991, Morey 1992, Foarde et al. 1996a).

The quality of surface seems to affect the fungal growth even when the surface is coated with a layer of dust. On porous materials, soiling levels of 5-10 g/m^2 have hastened fungal growth at 97% (Chang et al. 1996) but not **on galvanised steel** surfaces. However, much higher soiling (90-180 g/m^2) on the galvanised steel surface have supported fungal growth at 90-97% RH (Chang et al. 1996). With high soiling levels (100-200 g/m^2) on **unused insulation** materials, significant microbial growth has been detected at an RH range of 90-94% within a week, and at 85% RH after five weeks. In addition, accumulated dust and debris on **used insulation**, fibreglass duct board, and fibreglass duct liner supported fungal growth at 97% RH. A decrease in temperature decreased the growth rate. However, in six weeks the amplification of spores may achieve the same level at 23 and 12°C (Foarde et al. 1996b). The researchers concluded that conditions favourable to fungal growth in HVAC systems are common, and that moisture control is the most important preventive action (Chang et al. 1996, Foarde et al. 1996a-b).

Amount of microbial contamination is usually determined with **cultivation method** that also enables the **identification of the genera** of microorganisms. The determination of the fungal spore and bacteria counts can be done **from the dust sample** collected as described previously. The only restriction is that the mass of sample must be high enough, at least 100 mg, for reliable determination. In the method the sample is mixed and shaken up in a known volume of dilution water from which it is plated on suitable nutrient agar for bacteria and fungi. **Direct counting of spores or microbial cells** with aid of microscopy **is usually impossible** because of the high density of dust particle with various light reflectance properties in the samples. Cultivation method is also used for **water samples** from humidifiers or other water reservoirs. The **insulation and other soft material samples** are able to treat as dust samples.

The surface sample can be collected also by **swiping method**, in which a known area is swiped crosswise with a cotton wool stick wetted in sterile dilution water. The sample is cultivated as the dust sample. Both the methods gives results in **colony forming units per square meter (CFU/m^2)** if the dust sample is collected from a known area. Whatever the method is used for microbial analysis, attention should be paid for prevention of contamination of the samples during sampling and during treatment of the sampling instruments. Especially bacteria may be originated from the person who takes the samples.

Oil Residues

The HVAC-components are most often made of galvanised sheet metal, which needs corrosion protection to avoid hydroxylation of the zinc surfaces during storage and transport from steel mill. These viscous fluids form a sticky layer on the surface decreasing cleanliness and hygiene of manufactured components. Further, lubrication is needed to decrease friction between machine tool and the sheet metal during manufacture of some components with sharp bends or bows. A part of the lubricant remains as a thin layer on the interior surface of the product where it increases dust accumulation on the surface and serves as a potential growth media for microbes. Evaporation of hydrocarbons from oil residue decreases the perceived quality of the air passed through the ventilation system (Pasanen et al. 1995, Björkroth et al. 1997).

Two sampling methods have been applied to collect the oil from the sheet metal surface. In swiping method the sample area is swiped crosswise with glass or cotton wool sampler from an area of 100 cm^2 bordered with a template. The swiping sampler is prepared by immersing the swap in a test tube containing 2 ml of tetrachloroethylene (TCE) after which the excess solvent is pressed carefully back in the tube. In laboratory, the solvent is evaporated and the sample is dissolved in a known amount of TCE and total amount of oil components is analysed with a spectrophotometer.

Filter contact method is based on the pressing an immersed glass fibre filter on the surface with a constant pressure. The filter (5 cm x 5 cm) is immersed in tetrachloroethylene (0.036 ml tetrachloroethylene/cm^2), after which it is placed and pressed the surface to be sampled. The filter is pressed with a constant pressure device or against surfaces with irregular shapes with tweezers or by fingers over PTFE film to avoid contamination from fingers. After the sampling the filter is closed in a test tube and the analysis is performed similarly to the glass wool and cotton wool samples.

Summary

In many countries cleanliness of ventilation system has an increasing interest to maintain high quality indoor air and it offers many kind of business challenges like duct cleaning work and also for industry who manufactures the cleaning devices. Objective methods to evaluate cleanliness of HVAC systems are needed by building contractors and land lords to inspect if the HVAC systems need to be cleaned and by not least the cleaning companies for their quality control.

Surfaces in HVAC systems carry many kind of debris. Solid particles originate from building construction time or from outdoor air during the normal use of the building. Contaminants may contain also living cells or microbial colonies supported by exceptional moisture sources and also oil residues from the time of manufacture of the components. All these different groups of contaminants need the methods of their own. A list of them is expressed in the Table xx Note from the Table xx that the different methods have different efficiencies.

Table 1. Summary of the methods used for evaluation of cleanliness of HVAC systems.

Visual inspection	
Non-systematic inspection	No scaling for the cleanliness, subjective
Systematic	Grades for the cleanliness, semi-objective optical and electrical devices may be used to store the views and records

Quantitative methods for dust		
Method	Units	Note
Filter sampling	(g/m^2)	most common, repeatable
Cloth wiping	(g/m^2)	effective when used with solvent
Tape sampling	(g/m^2)	suitable for low levels ($<\sim 4$ g/m^2)
Gel tape sampling	(%)	need special device

Quantitative methods for micro-organisms		
cultivation of dust sample	(CFU/g)	identification of the cultivable species
cultivation of liquid sample	(CFU/ml)	
cultivation of swab sample	(CFU/m^2)	
counting of spores in dust sample	(#/g)	gives total spore count, needs a specific separation technique
Quantitative analysis of oil residues		
Filter contact method	mg/m^2	analysis by gaschromatograph of by IR-spectroscopy

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Appendix 5: The optimal operation conditions of filters in the HVAC system.

In setting operational parameters of an air handling system of a building, consideration needs to be given to whether the supply air will contain only filtered outdoor air, or if it will also contain a certain fraction of returned air and, what are the flow rates of supply, outdoor and return air. Optimisation of the operation of the system needs to take into account the changeable nature and concentration of outdoor particulate matter, variation in occupancy pattern of the building, the demands on the system to provide required indoor conditions (not only in terms of particulate matter concentration but also in terms of temperature and humidity), and finally in terms of energy consumption of the system. Due to the complexity related to a large number of factors, and in order to accommodate all the requirements that are sometimes conflicting, it is usually necessary to use models and software packages that would allow simulation of various conditions of interest. The outcomes of the simulation provide foundation for selecting appropriate management and control approaches in order to achieve a healthy, productive and comfortable indoor environment in a cost efficient way.

As an example, an output from a simple one zone mathematical model, for evaluation of the effect of various parameters, such as filtration efficiency, filter location, mixing factor, deposition velocity and others, on particle concentrations indoors is provided in Figure 1 (Jamriska et al., 2001). Indoor concentration was predicted for a hypothetical building representative of an office type environment, located near a busy road in an urban environment.

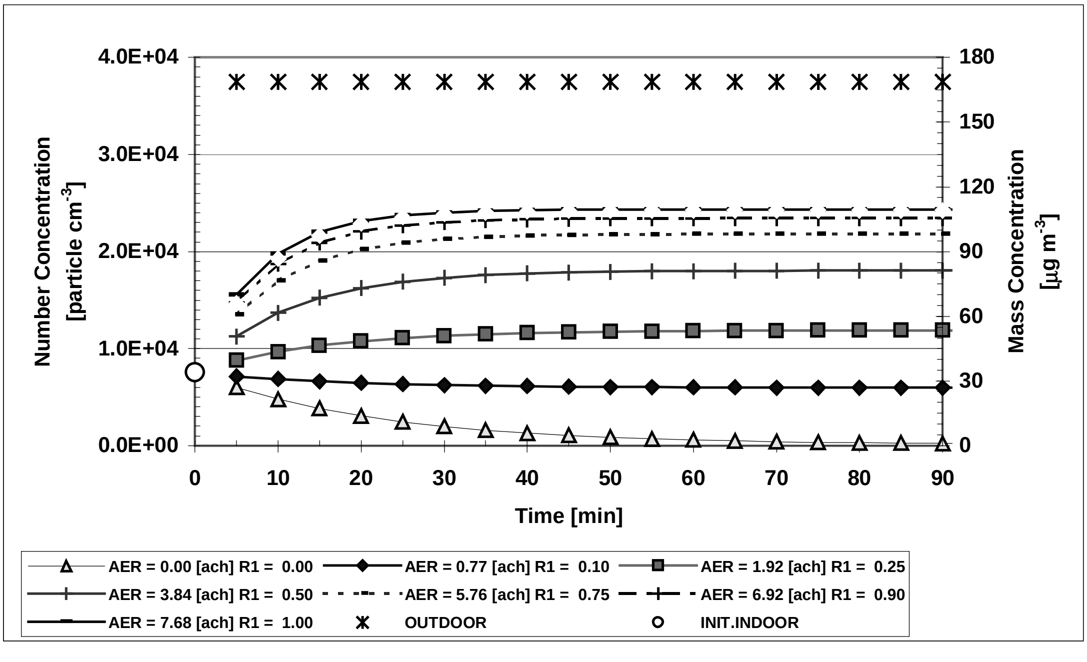

Figure 1. The time evolution of particle concentration simulated for a constant air ventilation system for a situation when the outdoor concentration is greater than the initial indoor concentration; AER is the air exchange rate and R1 is the ratio of the outdoor air to the of the supply air flowrates.

Figure 1 presents the time evolution of indoor particle concentration for a case of particle number concentration in outdoor air higher than in the indoor air and the air handling unit operating at a constant supply and variable outdoor and return air flow rates. It can be seen from Figure 1 that indoor concentration varies significantly depending upon the air exchange rate and contribution of return air to the supply air for this specific case.

This and other models are available as tools to optimise operation of the HVAC system in relation to the characteristics of outdoor air quality. For example, building simulation programs DOE-2 and ESP-r are recognised as industry standards in the USA and Europe for energy and airflow modelling, comfort and HVAC simulation (Clarke and Strachan, 1994; Hirsch, 2000). Indoor air quality models such as SHAPE, RISK, CONTAM, COMIS, MIAQ, VORTEX, FLUENT provide answers in terms of the indoor exposure, risk assessment, time and spatial variation in pollutant concentration and air movement (Spengler et al., 2000).

Despite the large number of existing mathematical models there is a need for improvement in terms of better model validation, accuracy, input requirements, and also a need for a development of new simulation tools capable of progressing with the new developments in the multi-disciplinary and complex field of indoor environments.

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Appendix 6: Accepted criteria for thermal, atmospheric and acoustic indoor environment in office and commercial buildings

This document should be a special part of the discussions during the initial part of the design phase (pre-design phase).

Table 1: Examples of criteria for thermal. atmospheric and acoustic indoor environment – office buildings

Building Categories	**Activi ty**	**Popul ation**	**Operative Temperatures °C**					**Max air vel.**		**Supply Of Two Step Filtrated Outdoor Air**		**Sound Pres-sure Level**	**CO_2**
Areas		**Densi ty**	**Summer**			**Winter**		**m/s**					
	(met)	**Occu-pants/ m²**	**Min**	**Max**	**Night min.**	**Min**	**Max**	**At 20°C**	**At 25° C**	**L/s per person**	**L/s per m²**	**dB(A)**	**ppm CO_2**
Different offices	**1.2**	**0.2**	20	24	15	20	22	**0.13**	**0.15**	**42**	**4.2**	**32**	**600**
Conference room	**1.2**	**0.1**	20	24	15	20	22	**0.13**	**0.12**	**16**	**8**	**32**	**600**
Educational	**1.2**	**0.5**	20	24	15	20	22	**0.13**	**0.15**	**16**	**8**	**32**	**600**
Reception	**1.2**	**0.1**	20	24	15	20	22	**0.13**	**0.15**	**42**	**4.2**	**32**	**600**
Entrance hall	**1.2**	**0.1**	20	24	15	20	22	**0.13**	**0.15**	**42**	**4.2**	**35**	**600**
Library	**1.2**	**0.1**	20	24	15	20	22	**0.13**	**0.15**	**-**	**6**	**32**	**600**
Cinema/auditorium	**1.2**	**0.5**	20	24	15	20	22	**0.13**	**0.15**	**16**	**-**	**32**	**600**
TV-studio/scene	**1.2**	**0.5**	20	24	15	20	22	**0.13**	**0.15**	**16**	**-**	**32**	**600**
Restaurant/bar	**1.4**	**0.35**	20	24	15	20	22	**0.13**	**0.15**	**16**	**9**	**32**	**800**
Shopping center	**1.4**	**0.07**	20	24	15	20	24	**0.15**	**0.20**	**15**	**-**	**35**	**600**
Hair dresser/beauty	**1.4**	**0.07**	20	25	15	20	25	**0.15**	**0.20**	**18**	**-**	**35**	**800**
Food/dry-cleaner	**1.4**	**0.1**	20	25	15	20	25	**0.15**	**0.20**	**-**	**8**	**35**	**800**
Bank	**1.2**	**0.07**	20	24	15	20	24	**0.15**	**0.20**	**-**	**8**	**30**	**600**
Printer/EDB	**1.4**	**0.3**	20	26	20	20	24	**0.20**	**0.20**	**-**	**7**	**35**	**800**
EDB-machinery	**1.4**	**0.5**	20	26	20	20	24	**0.20**	**0.20**	**-**	**7**	**35**	**600**
Tele/copying room	**1.4**	**0.5**	20	26	20	20	24	**0.20**	**0.20**	**-**	**7**	**35**	**600**
Wardrobe	**1.2**	**0.3**	22	24	15	20	22	**0.15**	**0.15**	**14**	**7**	**35**	**600**
WC-room	**1.2**	**-**	20	24	15	22	24	**0.20**	**0.15**	**30**	**-**	**35**	**800**

Table 2: Examples of criteria for thermal. atmospheric and acoustic indoor environment – office buildings

Building Categories	**Acti vity**	**Pop-Ula-Tion**	**Operative Temperatures °C**					**Max air vel.**		**Supply Of Two Step Filtrated Outdoor Air**		**Sound Pres-sure Level**	**CO_2**
Areas		**Den-Sity**	**Summer**			**Winter**		**m/s**					
	met	**Occu-pants /m²**	**Min**	**Max**	**Night Min.**	**Min**	**Max**	**At 20°C**	**At 25° C**	**L/s per person**	**L/s per m²**	**dB(A)**	**ppm CO_2**
Activity room	**4-5**	**0.3**	20	24	15	18	20	**0.15**	**0.20**	**30**	**-**	**35**	**800**
Shower	**1.2**	**-**	22	24	15	22	24	**0.15**	**0.15**	**30**	**-**	**35**	**800**
Archives/storage	**1.4**	**0.5**	20	24	15	20	22	**0.20**	**0.20**	**-**	**3**	**35**	**800**
Corridor	**1.4**	**0.05**	20	24	15	20	24	**0.15**	**0.15**	**-**	**4**	**35**	**800**
Cleaning	**1.4**		21	-	15	20	-	**0.20**	**0.20**	**-**	**5**	**35**	**800**
Canteen	**1.4**	**0.05**	20	24	15	20	24	**0.15**	**0.15**	**16**	**8**	**32**	**700**
Kitchen	**1.4**	**0.1**	20	26	15	20	24	**0.15**	**0.20**	**-**	**8/24 (6/21)**	**35**	**800**
Cold storage cham	**-**	**-**	4	6	-	2	4	**-**	**-**	**-**	**-**	**-**	**-**
Refrigerating ch	**-**	**-**	-24	-22	-	-24	-22	**-**	**-**	**-**	**-**	**-**	**-**
El.room (low volt)	**-**	**-**										**-**	**-**
Stairway	**1.4**	**0.05**	20	25	15	18	24	**0.20**	**0.20**	**-**	**2**	**35**	**900**
Lift machinery	**2.0**	**0.01**	15	32	15	-	-	**-**	**-**	**-**	**5**	**35**	**800**
Waste room	**2.0**	**0.01**	7	9	-	7	9	**-**	**-**	**-**	**6**	**35**	**-**
Ventilation	**2.0**	**0.01**	15	-	15	15	-	**-**	**-**	**-**	**6**	**50**	**-**
Cooling centre	**-**	**-**	15	27	15	15	24	**-**	**-**	**-**	**-**	**70**	**-**
El.techn. room	**-**	**-**	20	25	-	20	22	**-**	**-**	**-**	**-**	**40**	**-**
Parking	**-**	**-**	15	27	-	5	24	**0.25**	**0.25**	**-**	**3**	**40**	**-**
Production hall	**1.6**	**0.01**	16	19	15	19	22	**0.18**	**0.22**	**-**	**3**	**40**	**800**

Appendix 7: Checklist for the hygienic operation and maintenance of air-conditioning systems (according to VDI 6022)

	Action	Measure to be taken if necessary	Interval months	Hygiene inspection
1	Outside air inlets and air outlets			
1.1 1.2	Inspect for contamination, Inspect for damage and corrosion	Clean and rectify	12 12	
2	Central air handling units			
2.1	Inspect the air side for contamination, damage and corrosion	Clean and rectify	12	
2.2	Inspect for water formation	Clean, determine cause	6	
3	Air filter [1)]			
3.1	Inspect for impermissible contamination incl. odours and damage (leaks)	Replace the defective air filter if the most recent filter stage replacement took place not more than 6 months ago, otherwise replace the complete filter stage	3	
3.2	Check the differential pressure	Replace the filter stage	1	
3.3	Latest filter change in case of non regenerative filters, otherwise thorough cleaning. First filter stage Second filter stage		12, 24	
3.4	Check the hygiene condition			x
4	Air humidifiers			
4.1	Evaporation and recirculation pray humidifiers			
4.1.1	Inspect for contamination, damage and corrosion	Clean and rectify	1	
4.1.2	Check the bacterial count of the humidifier water (dip slides)	Where the bacterial count is > 1000 KBE/ ml, wash with cleaning agent, flush and dry the tank, disinfect if necessary	0.5	
4.1.3	Inspect atomiser nozzles for deposits	Clean or replace nozzles	1	
4.1.4	Inspect dirt traps for condition and functioning	Clean and rectify	6	
4.1.5	Check for flock formation at the bottom of the air humidifier tank	Clean tank	1	
4.1.6	Check the recirculation pump for dirt and coating of the inlet pipe	Clean the pump circuit	1	
4.1.7	Carry out a functional test of blow down device	Readjust blow down device	6	

	Action	Measure to be taken if necessary	Interval months	Hygiene inspection
4.1.8	Carry out a functional test of conductivity measuring cell	Rectify	1	
4.1.9	Carry out functional test of sterilisation system	Rectify	1	
4.1.10	Clean the air humidifier if a shutdown of more than 48 hours occurs	Wash with cleaning agent, flush and dry the washer tank	As re-quired	
4.1.11	Check of hygiene condition			x
4.2	Demisters			
4.2.1	Inspect for contamination, damage and corrosion	Clean to maintain functioning	1	
4.2.2	Inspect the demister for coating	Clean to maintain functioning where there is visible encrustation	1	
4.2.3	Check the hygiene condition			x
4.3	Vapour air humidifiers			
4.3.1	Inspect for contamination, damage and corrosion	Clean and rectify	3	
4.3.2	Wash with cleaning agent, flush and dry the humidifier chamber, disinfect if necessary		6	
4.3.2	Check for condensate precipitation in the humidifier chamber	Clean the vapour humidifier	1 (only during opera-tion	
4.3.3	Inspect the dirt traps for condition and functioning	Clean and rectify	6	
4.3.4	Check the vapour lance for deposits	Clean	6	
4.3.5	Check the condensate drain	Clean and rectify	3	
4.3.6	Functionally test control valve	Rectify	6	
4.3.7	Check the hygiene condition			x
5	Heat exchangers			
5.1	Inspect for contamination, damage and corrosion	Clean and rectify	3	
5.2	Inspect wet coolers, condensate tanks and demisters for contamination, corrosion and functioning	Rectify	3	
5.3	Functionally test the siphon	Rectify	3	
5.4	Clean wet cooler, demister and condensate tank		6	
5.5	Check the hygiene condition			x
6	Fans			
6.1	Inspect for contamination, damage and corrosion	Clean and rectify	6	

	Action	Measure to be taken if necessary	Interval months	Hygiene inspection
6.2	Cleaning of parts of the fan in contact with air and also the water drain to maintain functioning		12	
6.3	Inspect the drive	Renew the belt	12	
6.4	Inspect the flexible connection	Renew the flexible connection if defect	12	
7	Heat recovery devices			
7.1	Inspect for contamination, damage and corrosion	Clean and rectify	3	
7.2	Check the seal between the incoming air and outgoing air	Rectify	3	
7.3	Inspect the condensate tank and demister for contamination, corrosion and functioning	Rectify	3	
7.4	Functionally test the siphon	Rectify	3	
7.5	Clean the wet cooler, demister and condensate tank		6	
7.6	Rotating heat exchanger: Check correct pressure difference between supply and extract air		12	
7.7	Check the drive and the control system		12	
7.8	Check the hygiene condition			x
8	Air ducts and silencers			
8.1	Inspect accessible sections of the air duct for damage	Rectify	12	
8.2	Inspect the inside faces of air ducts for contamination and corrosion at 2 to 3 representative points	Determine cause, clean relevant section of air duct	122	
8.3	Inspect silencers for contamination, damage and corrosion	Rectify	12	
8.4	Check the hygiene conditions in the air duct at a representative point	Determine cause, clean relevant section of air duct		x
9	Air inlets			
9.1	Inspect installed perforated plates, wire mesh or sieves for contamination (random)	Clean or replace	12	
9.2	Replace filter pads in the case of:			
	filter class < F9		12	
	filter class ≥ F9		24	
9.3	Inspect air inlets which induct the room air and air outlets for the deposition of solids	Clean	As re-quired	
9.4	Clean the components through which the secondary air flows		12	
10	Cooling tower			
10.1	Inspect for damage and corrosion	Rectify	12	

	Action	Measure to be taken if necessary	Interval months	Hygiene inspection
10.2	Cleaning and draining the complete system		Twice yearly	
10.3	Check the blow down rate	Rectify	6	
10.4	Microbiological analysis of circulating water	Clean and disinfect	Twice yearly	
11	Dehumidifiers			
11.1	Inspect for contamination, damage and corrosion	Clean and rectify	3	
11.2	Inspect wet coolers, condensate tank and demister for contamination, corrosion and functioning	Rectify	3	
11.3	Functionally test the siphon	Rectify	3	
11.4	Clean wet cooler, demister and condensate tank		3	
11.5	Check the hygiene condition			x
12	Terminal devices			
12.1	Inspect terminal equipment with an outlet air filter for contamination	Replace the air filter, clean the equipment	3	
12.2	Inspect terminal equipment with a circulating air filter for contamination	Replace the air filter, clean the equipment	12	
12.3	Inspect the heat exchangers for dirt in the case of terminal equipment without air filters	Clean (vacuum cleaner)	6	
12.4	Clean the components through which the secondary air flows (without air filter)		12	
12.5	Replace air filter		24	
12.5	Do dampers work properly	Correct drive and position	24	
13	Cooling ceiling			
13.1	Inspect whether condensate does not appear		3	
13.2	Check the dew point sensors, control circuit inlet pipes and control valves for leaks	Rectify	12	
13.3	Check the expansion vessel			
14	Dampers			
14.1	Do dampers open and close correctly	Correct the positions of the blades		
14.2	Does the drive work properly	Correct the positions of the drive and of limit switches		

[1)] For air filters for terminal equipment refer to item 12 of this checklist.