INNOVATIONS IN VENTILATION TECHNOLOGY

21ST ANNUAL AIVC CONFERENCE
THE HAGUE, NETHERLANDS, 26-29 SEPTEMBER 2000

Determination of the dimensioning value of the airflow when designing ventilation systems

Mats P S Persson, PhD, Adjunct Professor

Chalmers University of Technology
Department of Building Services Engineering
Gothenburg
SWEDEN
Tel: +46 31 772 36 73
Email: maper@vsect.chalmers.se

Determination of the dimensioning value of the airflow when designing ventilation systems

Mats P. S. Persson, PhD, Adjunct Professor
Chalmers University of Technology, Department of Building Services Engineering, Gothenburg Sweden (phone: +46 31 772 36 73, e-mail: maper @vsect.chalmers.se)

Synopsis

Before starting to design an HVAC installation for treatment, supply and exhaust of air to and from a building the needs should be listed, transformed to requirements and their consequences analysed. Requirements lead to different amounts of airflow for their fulfilment. These needs for airflow should be calculated. The demand leading to the highest call for airflow will decide the airflow for which the equipment should be dimensioned - the dimensioning airflow.

List of symbols

$\dot{V}$	Flow of air, volume per time unit, m^3/s
c_p	Specific heat capacity, kWs/kg,K
ΔT	Temperature difference, K
$\dot{Q}$	Power, kW
ρ	Density, kg/m^3.

1. Background

What airflow should be used when decisions on sizes for fans and ducts etc in an air handling installation are made? Persistent use of airflows taken from codes will mean fulfilment of minimum requirements. To do so without reflecting what real needs and demands are can not contribute to the establishment of good will for ventilation technicians.

The motive to ventilate a space can principally be related to one or more of the following three categories **A**, **B** or **C**:

A. Exhaust of indoor generated pollutants
Ventilation is needed to hold the airborne pollutants in the indoor air at or below an acceptable level, which is done by the removal of emitted pollutants. These pollutants may be gaseous, inclusive of water in the form of vapor, or they may exist in the form of particles, for instance dust particles, spores, aerosols etc. The polluted air is transported from the indoor locality through the ventilation system.

Simultaneously air must be supplied. The supply air shall, of course, be less polluted than the exhaust air. Supply air taken from untreated outdoor air may not always meet the requirements for air quality. The quality of the supply air must be at least as good or, preferably, better than the acceptance level for indoor air. In order to meet this requirement the outdoor air may have to be cleaned and conditioned (filtered, heated, cooled, humidified, dehumidified) before being supplied to the indoor environment.

B. Thermal comfort

In cases where an indoor space is ventilated the flow of air can also be used for additional purposes. The room temperature will be affected if air is supplied with a different temperature. The airflow through a space may, therefore, be used to help control the temperature. If temperature control is the main reason for installating a ventilation system then it may be a call for an airflow that surpasses that needed to fulfil the requirement for pollutant control.

The supply of air must always be done in a manner so as not to jeopardise the thermal comfort. One criterion for thermal comfort is that the velocity of air must not be too high in areas where people occupy. The temperature in these areas must also lie within acceptable limits. To manage this the device for airsupply must be well designed and well situated. Furthermore, the supply air must not be too hot or too cold in relation to what is required by the persons or activities in the room.

C. Replacement of evacuated air

Still another reason for supplying air is plain balance of masses, i.e. to supply air to compensate for air that may, for instance, have been sucked out of the room. Examples on such airflows are

- Evacuation flows due to odour control (kitchen fans etc.),
- Through different types of equipment for exhaust control (fume hoods etc.),
- For combustion processes, i.e. furnaces,
- For protection purposes through fume cupboard and similar equipment.

Both the earlier referred reasons for ventilation, **A** and **B**, requires the existence of a balance between supply and exhaust airflows.

To consider the need for mass balance at the design stage will have effect on the level of airpressure at which this balance will be established in the erected building.

The supply of air should be accomplished by a number of designed measures planned by the HVAC-engineer. In this connection he has to take into consideration the flow of air - usually unintentional - that takes place through the building envelope. It is in the nature of such flows that they are uncontrolled. As a result comfort problems may arise if these flows are not properly balanced.

2. Balances

The reason **A** above could alternately be formulated as a request for massbalance for each type of pollution. Such a "pollutionbalance" will be utilised for calculation the amount of airflow that will be needed in order to meet the requirement. The reason **B** is a balance condition for energy. The reason **C** is already expressed as a balance condition for masses.

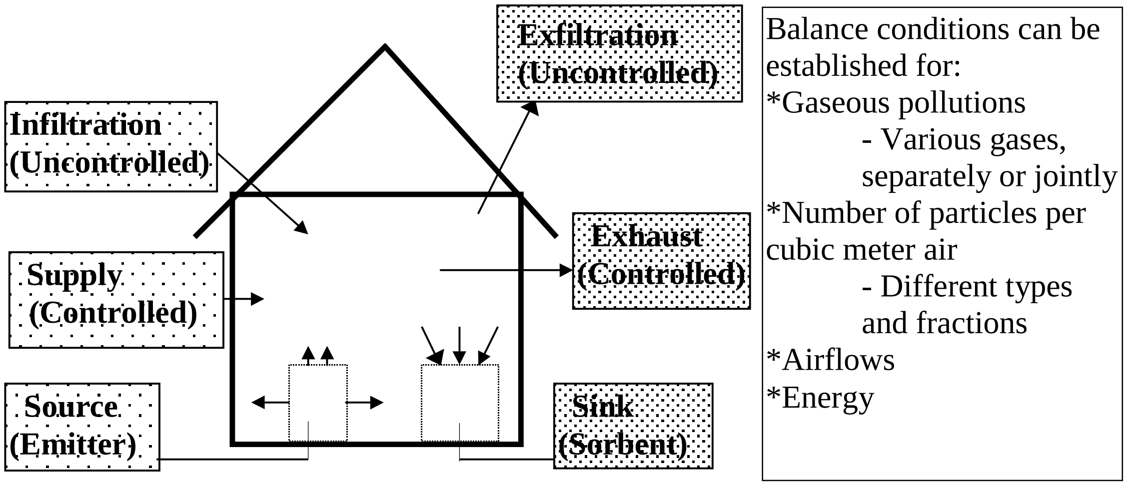


Figure 1. Illustration of alternative ways in which pollutants can be supplied or removed from indoor air.

3. Needs - requirements - consequences

A building is erected or refurbished in order to meet certain needs. These needs can emanate from human needs for a sound environment. (Formulated from aspects on hygiene, health and comfort.) There can also be needs to protect products and / or processes from the indoor environment. One example is the need for extremely clean air in the microelectronic industry. Still another reason is to protect humans from hazardous releases, i.e. toxic or biomedicine elements.

In order to meet all these needs we must be able to communicate what needs we have and what empasis we place to assure that these needs are met. To be able to do so it is an evident advantage if the need can be specified. The reason being that there are many actors involved at the creation of a building and misunderstandings can be avoided more easily if the needs are easily communicated, which they are if specified.

Through the formulation of needs as requirements two advantages are gained. One is that the needs will be specified and possibly so in measurable terms. The other advantage is that the word requirement sends a clear signal that it should be fulfilled. In short - What gets measured gets done.

When all the requirements have been collected they must be scrutinised. This scrutiny should be done in order to bring forward and discuss all the consequences, possibly to reconsider the needs or to (re-)formulate the requirements in an alternative manner in order to make it evident to all parties what is meant to be achieved by fulfilment of that requirement. Such an iterative process where **needs, requirements and consequences** are formulated and discussed can preferably be looped several times before the result of such a process is acceptable to all involved.

A presentation of the requirements that affects the design of the air handling devices for a building or space should be done. It gives an overview and at the same time it works as a check that all the requirements are collected. Normally this task is performed by the HVAC-engineer for the project even if in a formal sense it falls within the building owners responsibilities to formulate what he is purchasing and for what the authorities and future tenants will hold him responsible.

*Table 1. Proposal for tabulatory presentation of conditions for and requirements on ventilation. For each type of balance condition, **A**, **B** or **C**, the requirements should be given.*

Topic (Balance condition)	Source (emission, processes)	Sink (absorption, deterioration)	Background level in out-door air	Requirement (specified)	Requirement put forward by (specify)
A1. Gases **A2. Particles** **B. Heat balance** **C. Mass balance**					

4. Conditions for balance - gases

4.1 General considerations

Carry out the analysis for one gas at a time. In order to complete a calculation a number of data are needed. It is of course essential to know the acceptable level for the gas under consideration. Data about hygienic levels of acceptance for a great number of gases can be found in standards, for instance in AFS 1996:2 (in Swedish, issued by Arbetarskydds-styrelsen). Data given below are those which in the norm are noted as level of acceptance i.e. hygienic levels for exposure that could be endured without harm during a complete working day.

Table 2. Example of levels of acceptance for exposure to different gases in premises with different types of activities.

Gas	Examples of activities / processes where the gas may emerge	Level of accept. ppm.
Nitrous Oxide (laughgas)	Hospital	100
Chloroform	Laboratories, hospital	2
Acetone	Paint industries, cosmetic industries	250
Ammonia	Cooling, sport arenas etc	25
Benzene	Chemical industries, refineries	5
Trichloretylen	Cleaning fluid in industry	20
Formaldehyde	Gluing in wood related industry	0,5
Radon	Mining industry, housing	see text below
Carbon Dioxide	Fermentation processes	5 000
Carbon Monoxide	Auto workshops	35

Please note that this is a selection of data, which means a considerable reduction of information and addition of examples for locations where the gases may emerge.

By a simple calculation it is possible to transform the requirements on levels of concentration for radon, which normally is expressed in Becquerel per cubic meter (Bq/m^3), to a requirement for maximum gas concentration expressed in more common units, for instance in parts per million, ppm. Through this transformation the required airflow to create (at least) the acceptance level for radon can be calculated in the same manner as for other gases.

The relation is

$$\boxed{1\ Bq/m^3 = 19{,}05 \cdot 10^{-15}\ \text{ppm radon}}$$

The next step in the analysis is to establish or estimate what pollutants are supplied to the air from sources inside the building. Emission of gases may depend on type of activity, it may be emitted from persons present or it may have a source in building material or surface coatings.

Establish then for the gas under consideration, the content that untreated outdoor air holds in terms of so called background level. In order to get information on what gaseous pollutants exist and at what levels one can for instance:

- perform own measurements (over longer time periods - day/days),
- seek results from local measurements done by municipalities or state initiated organisations
- seek data in literature.

Once these data have been gathered one can, with use of the so-called dilution equation, establish what airflow is needed in order to reach an air quality better or at least as good as the required level. Example of results from such calculations will be shown below. In this example the effects that plants have on the gaseous content of air has been taken into consideration.

4.2 Example - Plants

Plants have the ability to do the reverse to what humans do, namely to assimilate carbon dioxide and to release oxygen. This is done in the photosynthetic process that forms the basis for our life on earth. Data for this process – assimilation of carbon dioxide and release of oxygen - are scarce when it comes to engineering purposes.

One source of data on this effectiveness of transformation says that the assimilation of carbondioxide lies in the interval 1 - 3 g/h, per square meter of leaf (only one side of a leaf is accounted for). In order to reach this effectiveness there is a requirement for illumination with the power 200 - 400 W/m^2 (measured on a horizontal surface). Such an illumination can be reached if the plants are placed near to a window. If the plants are to be illuminated by artificial light the power supplied must be considered (as must the effects of absorbed sunlight through windows) when establishing the overall heat balance.

The absorption rate of plants for carbon dioxide increases with rising concentration of carbon dioxide in the air. An increase in concentration of carbon dioxide from 350 ppm to 900 ppm will lead to an increased absorption rate with the same plants and at the same level of lighting from 1 - 3 g/h, m^2 to 2 - 6 g/h, m^2. High levels of concentration for carbon dioxide will consequently lead to rapid growth. This observation has lead to utilisation of artificial supply of carbon dioxide in greenhouses in order to promote growth. The air we humans exhale contains carbon dioxide up to levels 2 - 3 %, i.e. 20 000 - 30 000 ppm. Based on these facts it is no wonder that we are given the recommendation to talk to our domestic plants in order to make them thrive!

In the computations made to support this paper it has been assumed that both source and sink have capacities constant over time. In order to show the effect the plants have in absorbing carbon dioxide a number of calculations have been made with two different absorption rates; 2 g/h, m^2 and 6 g/h, m^2.

How large (one sided) leaf area does an ordinary indoor common plant have? In an actual case the one-sided leaf area for a plant *Fikus benjamina*, a commonly used plant in office environment, was measured to approximately one square meter (1000 leafs á 10 cm^2). In the calculations related here the number of plants were given as 0,8 per square meter floor area and the number of people to 0,4 per square meter floor area.

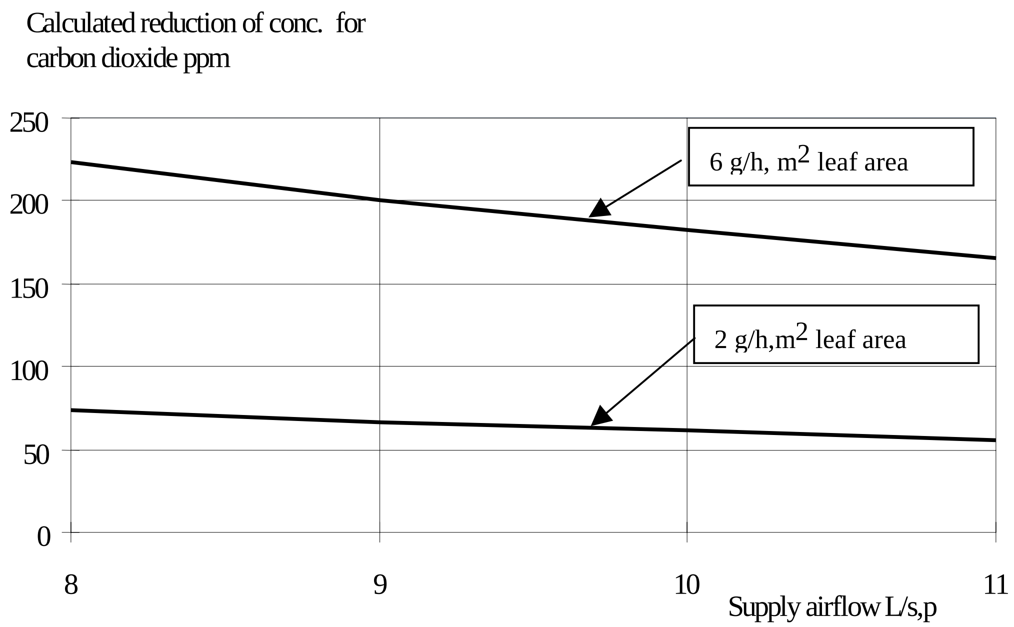


Figure 2. Illustration of the reductive effect that plants with varied absorption rates for carbon dioxide have on the level of carbon dioxide in the indoor air. The example is an office space with room height 3,2 m and with plants and people as stated in the text.

It needs to be pointed out that Carbon Dioxide in a room ventilation context normally is used as an indicator for polluted, smelly, air. To reduce the indicator without giving a remedy towards the effects that the indicator is supposed to point out is not a rational behaviour.

Presence of plants indoors has effects leading to the reduction also of other gases than carbon dioxide. It is however very difficult to obtain quantitative data for such effects linking specific plants to specific gas reduction capacity. Plants also emit gases that can course allergic or asthmatic reactions from inhabitants.

In order to be able to constructively contribute to the use of plants as a mean to improve the indoor air quality, i.e. to use the good effect and avoid the negative ones, we need better knowledge of these effects. Much research on plants has been carried out and is reported in textbooks and articles. It is however difficult from this information to extract

- which gases are absorbed and emitted from different specified plants
- quantitative data on these effects (source and sink strengths per specified type of plant and related to size of plant so that required size or number of plants can be calculated in order to reach the desired effects).

The interest to utilise plants as a mean to treat air for better quality is rising. Data of the above outlined type will undoubtedly be presented in a near future.

5. Conditions for balance - particles

A hint of the size of particle mass in outdoor air is given in the below-related table 3. Please note that the total mass and gives no information on how this mass is distributed between different sizes of particles.

Table 3. Typical data for total mass of particles in outdoor air in different areas.

Type of area	Mass of particles, mg/m^3
Industrial area	0,1 - 10
Industrial town	0,2 - 5
Large city	0,03 - 0,3
Small city	0,02 - 0,1
Urban area	0,01 - 0,1
Desert	0,1 - 700

Data about how particles may be classified in different particle fractions can be as given in the example below, table 4.

Table 4. Example on distribution of particles in outdoor air relative to particle sizes

Particle size, interval, µm	Particle relative distr., weight, %	Particle distribution, number per cubic meter
30 - 10	28	1000
10 - 5	52	35 000
5 - 3	11	50 000
3 - 1	6	210 000
1 - 0,5	2	1 350 000
<0,5	1	18 300 000

Different activities cause different rates of particles being airborne. The following figure 3 is taken from a catalogue of a company that manufactures filters. The figure is included here to illustrate how strengths of sources for particle emittment can be estimated.

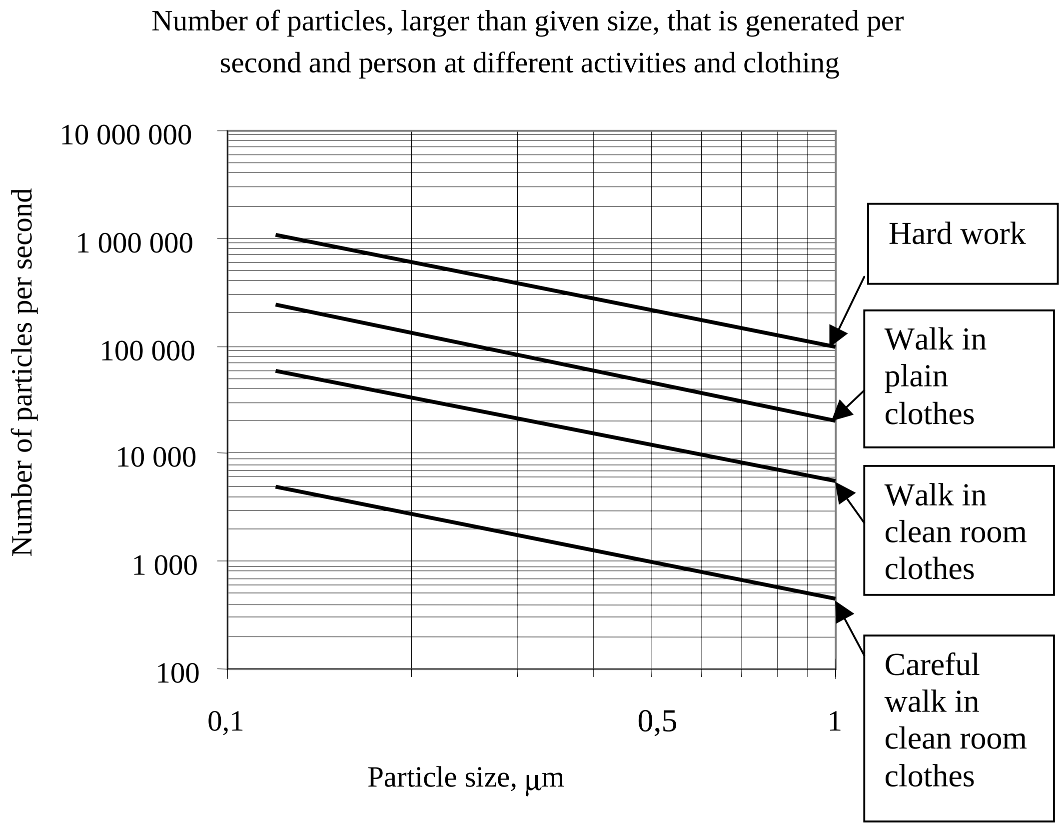


Figure 3. Example of particle generation (sources). [Courtesy of Camfil.] The four curves indicate particle generation at different activities and clothing.

In order to be able to select method for elimination of particles from air it is important to know the number of particles within different particle size fractions. The reasons being that different means for elimination have effectiveness that varies with particle size. Resent research also shows an increased interest to relate the negative effects from exposure to particles to the number of particles in different size fractions.

Note that request for a certain technical solution, for instance filtering, is an indirect way of posing a requirement. This way to express a requirement has possibly been used because there has been no other established way to express a requirement for "ordinary" premises. This is in contrast to "special" premises, such as clean rooms, for which there exists an established way to specify the highest number of particles that are acceptable. Clean rooms are used in laboratories and industries for instance for the manufacturing of electronic components. For such premises the demands for clean air is often expressed in different classes. The number given in a classification sometimes stands for the highest acceptable number of particles per cubic foot of air. The particles counted are often those with a diameter $\geq$0,5μm. This way to pose a requirement is illustrated in table 5.

Table 5. Requirement levels for highest number of particles ≥0,5μm

Class	Number of particles per cubic foot	Equivalent number of particles per cubic meter
10	10	350
100	100	3 500
1000	1000	35 000
10 000	10 000	350 000

This manner to specify highest acceptable number of particles can be used also for other particle fractions. One attempt to do so is shown in figure 4.

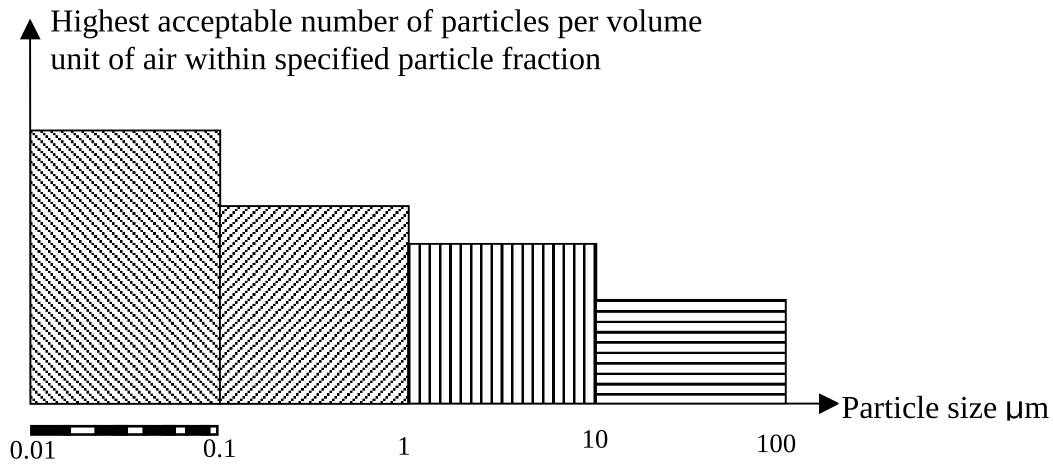


Figure 4. Exemplification on how requirements for highest number of particles per volume unit of air can be specified for different particle fractions.

The scale for the y-axes has purposely been left out. The reason is to create a void for innovations for those that find the proposed method to specify requirements worth while to develop. The aim for the methods developed along these lines should be that it is simple to apply and reasonably correct and thereby will be used by the professional engineers.

The use of number of particles in specified particle sizes and in specified volumes of air makes the proposed method for calculation parallel to the method employed for calculation of gas concentration. The different steps in such a calculation are outlined in reference [1] along with some illustrative examples.

6. Conditions for balance - flow of air to create and maintain an acceptable thermal indoor climate

Air can be used for transfer of heating or cooling power. Let the power to be transferred with air be marked $\dot{Q}$ (kW). The specific heat capacity for air is denoted with c_p (kWs/kg, K). The air density is given as ρ (kg/m^3). The difference between the supplied air and the air in the space, the indoor air, is given as ΔT (K). Based on these data the airflow $\dot{V}$ (m^3/s) required to convey the power $\dot{Q}$ (kW) can be calculated.

$$\dot{V} = \frac{\dot{Q}}{\rho \cdot c_p \cdot \Delta T} \qquad ...(1)$$

A simple enough formula, well known to practitioners, who also know that the difficult part normally is to determine the amount of power, $\dot{Q}$ (kW), which is to be transferred.

7. Conditions for balance - air volume

Air is purposely extracted out of premises by draughts caused by mechanical systems (fans) or by temperature and air pressure differences (self-draught). Air is also purposely extracted through process ventilation systems in order to protect people or products from contact with harmful or polluted air. Air is also being supplied and extracted involuntarily by leakage through cracks and crevices etc.

Irrespective of the manner in which air has been extracted from a space the same amount must be supplied to that space. Ultimately there will be a balance between in- and outgoing air volumes, but it is advantageous to arrange for that balance to happen in a planned manner. Problems may otherwise arise from excessive over or under-pressures that in turn may cause problems with moisture transfer etc.

In the process of establishing such a balance all the airflows in and out of space must be tabulated and summed up in the appropriate flow. At the design stage the accuracy of estimated airflows is usually so rough that a balance based on mass flows does not differ in any essential sense from a balance of airflow based on airvolumes. It is therefore recommended that the balance of in- and outgoing airflows be done with these more easily assessable air volumes. The risk is otherwise that a balance check is not done at all.

Consequent to this line of argumentation the equation for check of balance can be formulated as follows. The equation is formulated thus in order to support the active search for supply airflow leading to balanced conditions.

$$\dot{V}_{\sup ply} = \Sigma \dot{V}_{out} - \Sigma \dot{V}_{leakage} \qquad ...(2)$$

This is just a principal outline of the equation. It is written to illustrate how the amount of supply air can be calculated when all the outward flows have been summed up and the uncontrolled supply airflows have been estimated and deducted.

The alternative to abstain from this check and, passively, hope that what is missing in balance will be supplied through leakage is an alternative that should be avoided. Lack of balance between exhaust and supply airflows will lead to pressure differences, which in turn will lead to;

- Uncontrolled flows and resulting from them problems with thermal comfort. (Draughts, i.e. airflows with high velocities and with colder air.)
- Energy losses (Uncontrolled flows makes it impossible to exchange heat between in- and outgoing airflows.)

- Damages as a consequence of moisture condensations.
- Airflows leading to sound effects or difficulties to operate doors etc.

8. Presentation of calls for airflow relative to requirements

To determine the required amount of air that should be supplied to a building, a number of situations must be considered. Different external environmental conditions combined with contamination of the indoor air from processes or from inhabitants constitute different requirements for supply and removal of air. The aim of this paper is to present a logical approach for the estimation of the lowest amounts of air supply and removal air that satisfy the most severe demand.

Different steps can be distinguished in order to reach this goal.

- First the demands are gathered and transformed into requirements in a dialogue with the intended user of the premises. Note that no technical solutions are discussed at early stages of this process.

- Second the condition of outdoor air is established. The contamination of the indoor air from inhabitants, ongoing processes or from other sources are established or estimated.

- For each type of pollutant, gaseous or particulate, the required amount of supply air is calculated using equations for dilution of contaminated air with cleaner air.

- The need of fresh air to make up for air that is sucked and blown out of the building. The evacuated air may have been used voluntarily due to the need for air barriers, for transportation, for furnaces, etc. or involuntarily due to air leakage.

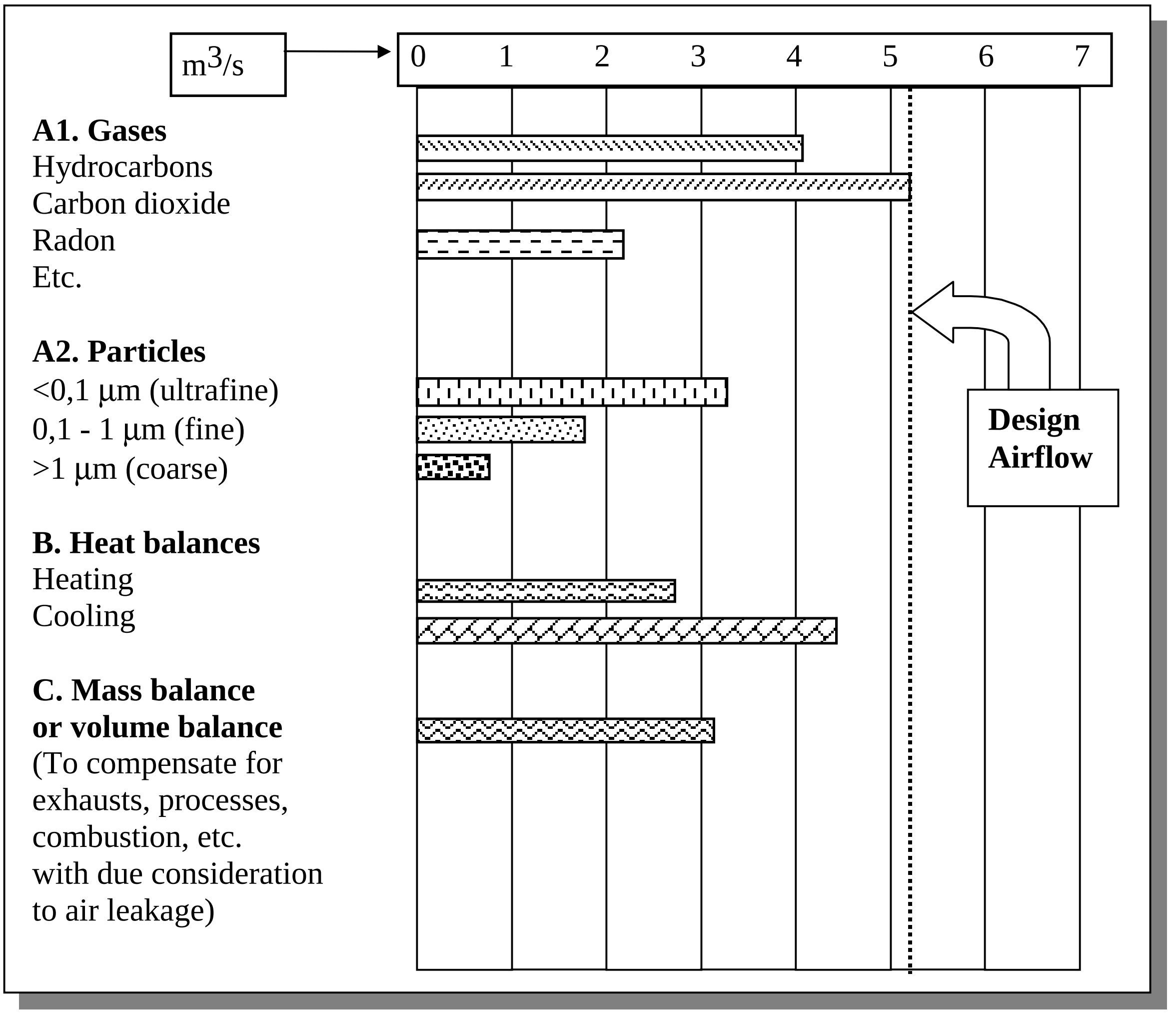
- When air is used for heating or cooling purposes, the amount of air to carry the required heat- or cooling-load must be calculated.

- Finally all the required demands for air supply are gathered and compared. The most severe demand for air supply is the one for which the air handling system should be dimensioned.

The final result of these efforts is presented in graphical form. The example presented below, for a given space and known activity, is totally fictitious but illustrates the principle for display of results.

Table 6. Example on how calls for airflows relative requirements can be presented.

Demands for air supply.
The highest demand is called the design airflow.



The scale used can be chosen at the designer's leisure. Note that if a dimension like air change per second or hour is chosen the air volumes in absolute values varies between different spaces. Such values must then be modified in order to make them additive.

The recommendation given here is to avoid the use of "rules of thumb" for the selection of design airflow and instead use the above-proposed systematic approach.

9. References

[1] Persson M.: (in Swedish) Design airflow. Methodology for determination of design airflow when dimensioning plants for air treatment. 132p.
Document D50: 2000, Institution for Building services Engineering, Chalmers University of Technology, SE-412 96 Göteborg