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PAPER 12

VENTILATION REQUIREMENTS AND DEMAND CONTROLLED VENTILATION

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LIST OF SYMBOLS

GW	material constant for particle board
T	temperature [K]
V	volume $[m^3]$
$\dot{V}_{CO_2}$	volume flow of CO_2-output $[\frac{l}{h}]$
a	particle board (pb) load $[\frac{m^2_{pb}}{m^3_{room}}]$
c	pollutant concentration [ppm]
$\dot{m}_W$	mass flow rate of water [g/h]
$\dot{m}^*_W$	specific mass flow rate $\dot{m}_W/V_r$ $[\frac{g}{hm^3_{room}}]$
n	hourly air charge rate $[\frac{1}{h}]$
ϑ	temperature [°C]
φ	rel. humidity [-]

Indices

i	indoor
o	outdoor
r	room

SYNOPSIS

In order to avoid demage to the health of occupants, annoyance or reduction in amenity and demage to the building fabric the concentration of indoor air pollutants has to be held below pollutant specific levels. One appropriate measure for the control of concentration is ventilation. In several national and international activities in the past, among others in the IEA's Annex IX "Minimum Ventilation Rates" and standardization efforts in Germany and other countries, ventilation rates have been defined which should meet both indoor air quality (iaq) requirements and energy conservation. The necessary air flow rates are, depending on the type of pollutant and national conditions, usually based on an average occupancy of persons in the room; they vary in a range of 30-40 m^3/h and person. For comfort reasons the minimum ventilation rate necessary to maintain acceptable indoor air quality (iaq) depends on many influencing factors especially on the number of persons, seasons, time of the day etc..
Ventilation rates exceeding the real and actual demand are not energy economic. A general view of iaq requirements is given.

Natural ventilation systems are compared to the requirements of the proposed ventilation strategy. A state of the art is given for the use of simple ventilation devices. For conditions in the Federal Republic of Germany the arguments and the advantages for a ventilation strategy consisting of a basic ventilation for non-occupied rooms with an additional rate depending on the number of persons and their activity are outlined. Dominant influence factors for both basic ventilation and additional ventilation are pointed out.

1. INTRODUCTION

Table 1 shows contaminants identified as being of main concern for indoor air, their source and the influences on either occupants or building fabric. All these single influence parameters are of growing interest and today deeply investigated and published in technical journals.

	depending on							
influence parameter on iaq	independent on number of persons 3)	number of		the building's			certain activ. like painting, carpeting, repairs, cleaning	weather
		pers.	and their activity	insulation	furniture	environment		
moisture 1)	x	x	x	x				x
carbon dioxyde 2)		x	x					
body odour 2)		x	x					
formaldehyde 2)	x				x		x	
organic compon. 2)	x				x	x	x	
tobacco smoke 2)			x					
radon 2)	x					x		

Tab. 1: Dependence of influence parameters on indoor air quality (iaq)

1) may cause damages to the building fabric and may cause health problems to sensitive persons
2) may cause health problems to occupants
3) usually not persons or their activities giving rise to emissions

The objective of this paper is to weight these parameters, to inquire the impact of each parameter on iaq, and to find the most dominant parameters for monitoring and controlling purposes.

2. VENTILATION REQUIREMENTS

For energy savings the air flow rate through a room should not overshoot the air flow rate necessary to maintain good indoor air quality, but it also should not be lower to guarantee well-being of occupants and prevent damages to the building fabric. As nearly every room in a house is frequented by the occupants at specific times of the day, there are always times when a room is not occupied and where ventilation rates can be shut down due to smaller amounts of emission. We will call this minimum ventilation rate "basic ventilation".

2.1 Basic Ventilation

For non-occupied rooms there are still indoor generated contaminants whose concentration has to be kept under a specific level.

2.1.1 Moisture Production

Water is evaporated by e.g. open surfaces (aquarium), flowers, wet clothes etc. The ventilation rate depends on the strength of water vapor released, the allowed rel. humidity inside the room depending on the interior surface temperature of the walls influenced by the insulation (thermal bridges!), and on the weather conditions outdoor temperature and humidity. At low outdoor temperatures the incoming air can remove much more indoor generated moisture than at higher outdoor temperatures. The variation of the relative humidity as a function of outdoor temperature for 13 locations distributed in the Federal Republic of Germany is listed in the German standard DIN 4710(3). An estimate for interior surface temperatures of walls which meet the German standard of minimal insulation requirements DIN 4108(2) has been published by Erhorn et al(4). Temperatures for non-occupied rooms vary between 16° and 22°C and may reach 14°C in bedrooms during wintertime.

Based on these information it is straightforward to calculate the necessary air flow rates to avoid surface condensation for the above specified boundary conditions. Figure 1 shows the so calculated air flow rates per 1 g/h water vapor production in a room versus outdoor temperature with indoor temperature as parameter. The range of outdoor air humidity as a function of outdoor temperature according to DIN 4710 results also in a range for the calculated air flow rates. Fig. 1 also indicates, that the specific air flow rate $\frac{\dot{V}_o}{\dot{m}_w}$ slightly decreases when outdoor temperature increases from -15 to 5°C. At higher outdoor temperatures the specific air flow rates increase rapidly. For reduced room temperatures the specific air flow rates increase due to lower indoor surface temperatures of the walls. Appendix 1 shows the generalized calculation procedure.

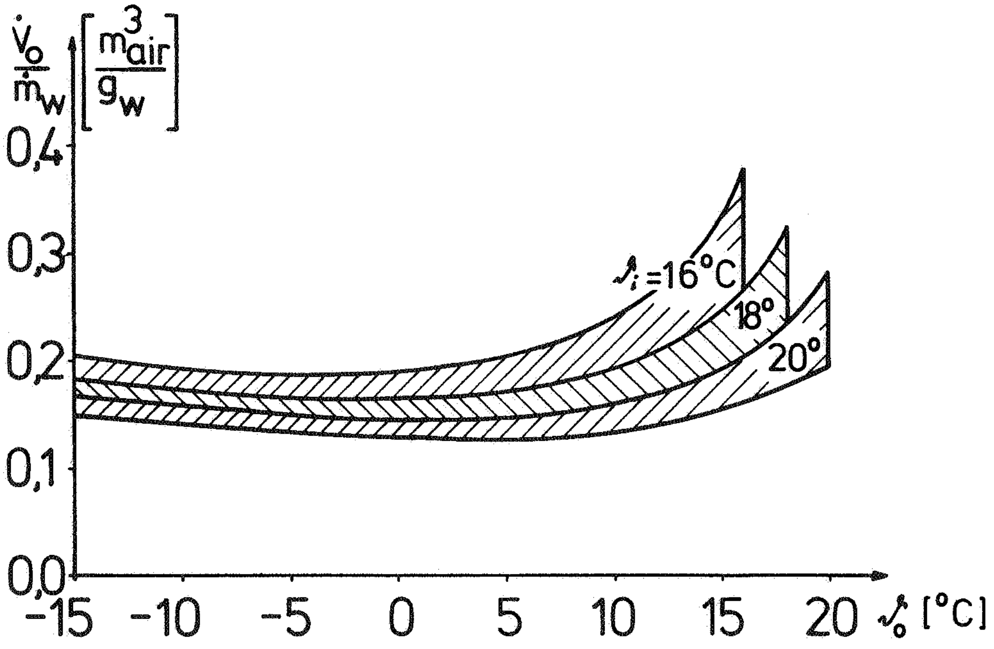

Fig. 1: Calculated outgoing air flow rates per 1 g/h water vapor production for avoiding condensation on interior wall surfaces

Therefore, a night switch back of a heating system to save energy will not decrease ventilation heat losses in the same magnitude than transmission heat losses if the then required higher ventilation rates at lower indoor temperatures are realized. As shown in figure 2 a reduction of the ventilation heat demand is only achieved at outdoor temperatures above 0°C.

Although the air flow rate has to be increased at lower indoor temperatures the smaller temperature differences $\vartheta_i - \vartheta_o$ are responsible for this reduction. When outdoor temperatures are below 0°C, the higher air flow rates are dominant and the result is an even higher ventilation heat demand. This graph is only partly true. Night switch back is a dynamic process and interior-wall-surface temperatures will not follow the change in indoor air temperature without hysteresis due to the inertia of the system.

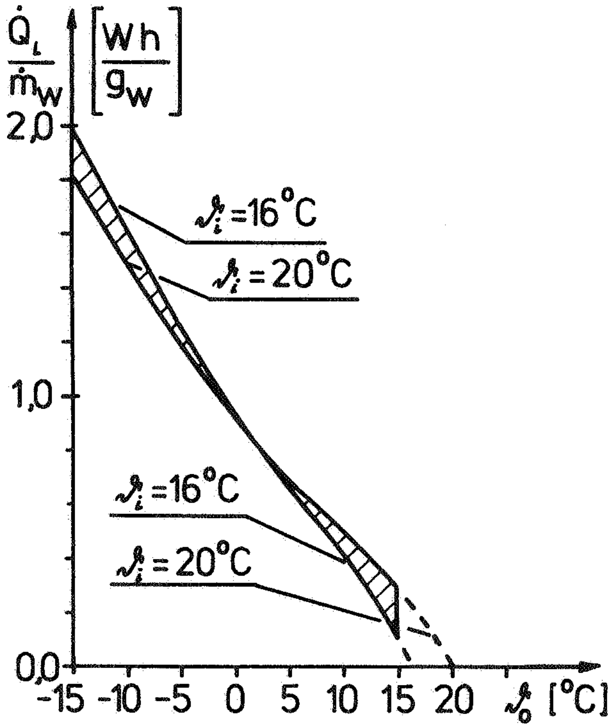

Fig. 2: Specific heat demand for ventilation (related to an evaporation rate of 1 g water per hour) for 2 indoor air temperatures with mean values of $\frac{\dot{V}_o}{\dot{m}_W}$ according to figure 1

2.1.2 Formaldehyde emission

Formaldehyde HCHO is mainly released by furniture made of particle board. In the Federal Republic of Germany only particle board of emission class E1 is allowed in prefabricated houses and for the production of furniture. Investigations of Mehlhorn[12] show that the emission of HCHO depends on a material constant, the room temperature and relative humidity, the air flow rate and the particle board load in the room. According to Fischer et al[9] an average value for the load factor of german houses is

$$a = 1 \ \frac{m^2_{\text{particle board}}}{m^3_{\text{room}}}$$

The load factor 'a' may rise to values of 2 for rooms with a high packing fraction of furniture. The emission of HCHO increases with increasing temperature, humidity, material constant, load factor and air flow rate. The calculation procedure of minimum ventilation rates to keep indoor HCHO concentration below a specific level is outlined in Appendix 2. For regulatory purposes it is recommended to limit the indoor air concentration to values below the experimental no effect level by applying a safety factor. This concentration is called "Acceptable Indoor Concentration, AIC", introduced by Fischer[8]. The Federal Health Office of Germany recommended an AIC for formaldehyde of AIC_{HCHO} = 0,1 ppm (= 0,12 mg/m^3).

2.1.3 Comparison of minimum air change rates for removal of moisture and formaldehyde

Water vapor production of non-occupied rooms and HCHO emission vary considerably according to the kind of room. To get an idea of the magnitude of the considered minimum air change rate (ACR) two cases are considered:

a) a non-occupied bathroom with a water evaporation rate of
$\dot{m}^*_W = 3\ [\frac{g}{h \cdot m^3_{room}}]$
representing - an open water surface of 0,4x0,4 m
- or 0,7 kg wet towels
- or 2-3 pot-plants

$V_{room} = 10\ m^3$; $\vartheta_i = 16\text{-}20°C$; $\varphi_o(\vartheta_o)$ according to DIN 4710 (see Appendix I)

particle board load factor $a = 0{,}5\ \frac{m^2}{m^3}$
φ_i calculated by eqn. 5, Appendix I, $AIC_{HCHO} = 0{,}1$ ppm

$$\dot{m}^*_W = \frac{\dot{m}_W}{V_r}$$

b) a living room with a water evaporation rate of
$\dot{m}^*_W = 2\ [\frac{g}{h \cdot m^3_{room}}]$
representing for example - 12 pot-plants
- or an Aquarium of 1 m x 0,6 m

$V_{room} = 60\ m^3$; $\vartheta_i = 16\text{-}22°C$; $\varphi_o(\vartheta_o)$ according to DIN 4710, see Appendix I,
particle board load factor $a = 1{,}0\ \frac{m^2}{m^3}$
φ_i calculated by eqn. 5, Appendix I, $AIC_{HCHO} = 0{,}1$ ppm

Figure 3a and 3b show minimum ACRs at 3 outdoor temperatures to either remove moisture or formaldehyde. The shaded areas indicate the range of ACRs due to changes in outdoor air humidity and indoor air temperature. The hourly ACRs in the bathroom according to figure 3a to keep HCHO concentrations below 0,1 ppm are equal or less than the hourly ACRs to remove moisture. This is due to the small load factor of $a = 0.5\ \frac{m^2}{m^3}$. The significant decrease in HCHO emission at $\vartheta_o = -10°C$ is due to the small allowed relative indoor humidity to avoid surface condensation. With a relatively high evaporation rate of water of $\dot{m}^*_W = 3\ \frac{g}{hm^3_{room}}$ moisture is the dominant factor.

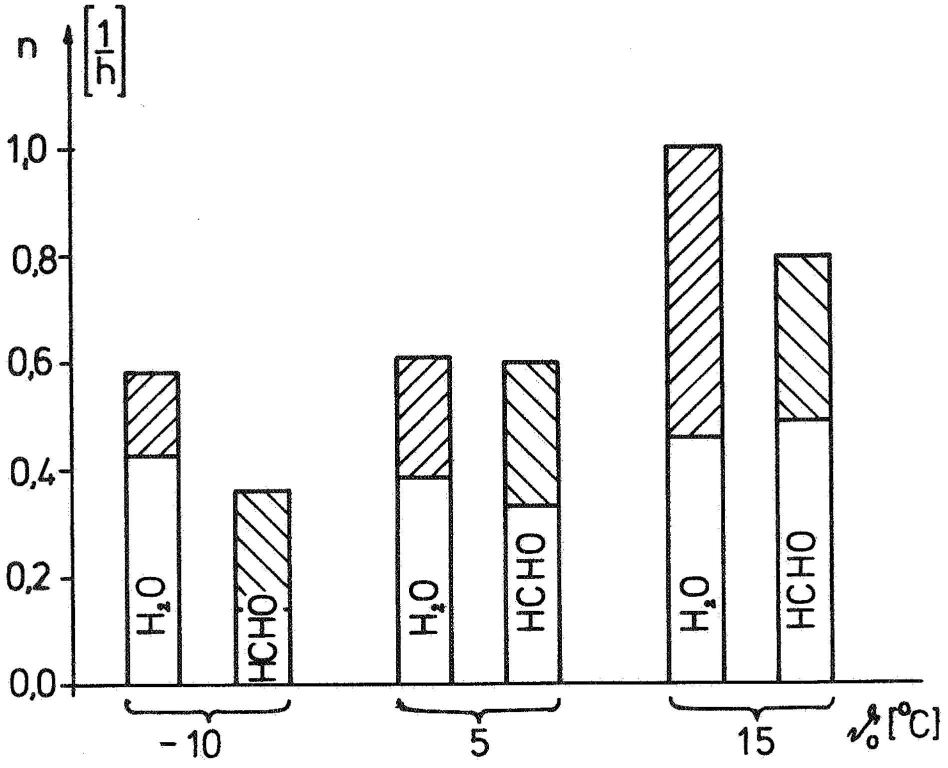

Fig. 3a: Hourly air change rate to remove moisture or formaldehyde in a bathroom

V_r = 10 [m³]; $\dot{m}_w^*$ = 3 $[\frac{g}{hm^3}]$; ϑ_i = 16-20°C

a = 0,5 $[\frac{m^2}{m^3}]$; AIC_{HCHO} = 0,1 ppm

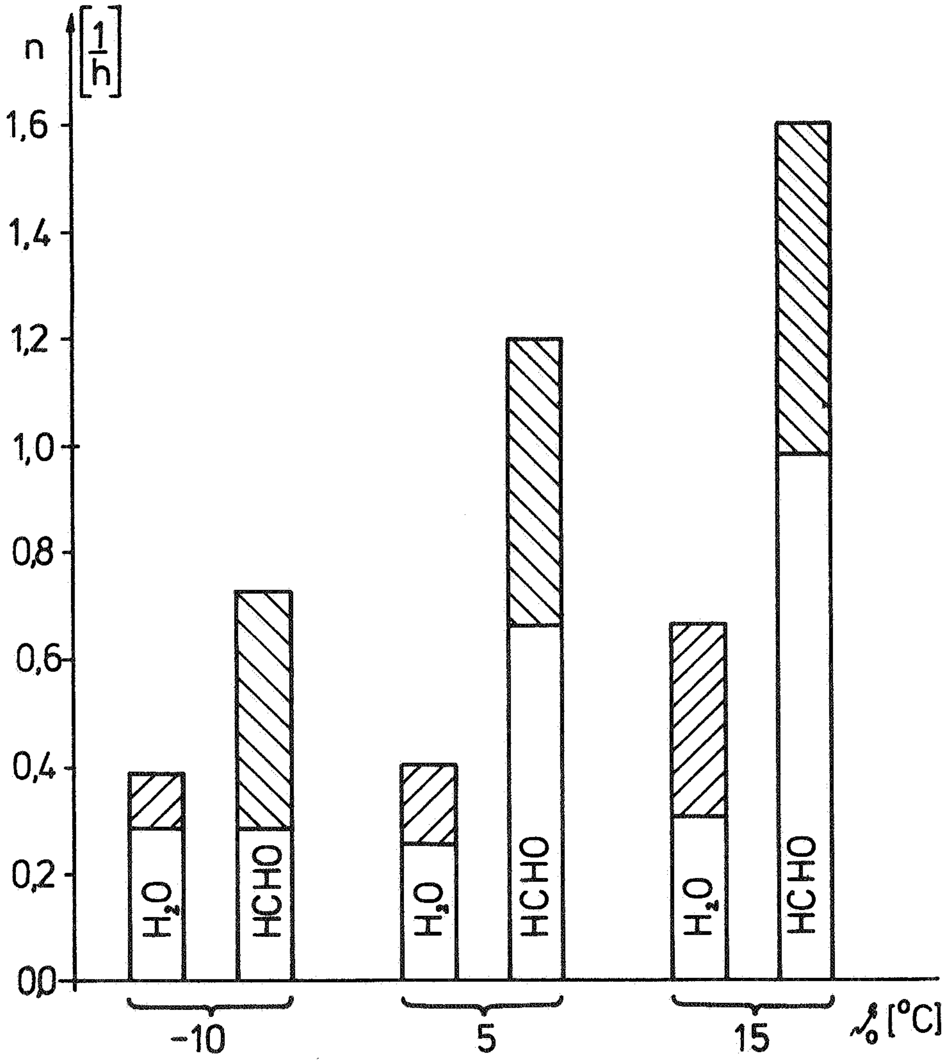

Fig. 3b: Hourly air change rate to remove moisture or formaldehyde in a living room

$V_r = 60\ [m^3]$; $\dot{m}_W^* = 2\ [\frac{g}{hm^3}]$; $\vartheta_i = 16\text{–}20°C$

$a = 1\ [\frac{m^2}{m^3}]$; $AIC_{HCHO} = 0{,}1$ ppm

The same calculation procedure applied to an average living room with a load factor a = 1 $\frac{m^2}{m^3}$ and a room volume of 60 m^3 shows a reverse behaviour. Due to a smaller evaporation rate of water and a higher load factor formaldehyde is the dominant parameter.

It should not be the objective of ventilation to remove indoor generated contaminants like HCHO or PCP, the primary step should be either to avoid emitting materials or to reduce their emission rates. However, based on emission standards which are valid at this time in the FRG it can happen that HCHO concentration reach irresponsible levels as it is indicated in figure 3b.

Another example may emphasize the importance of a basic ventilation rate. If there is no ventilation ($n=0.0\frac{1}{h}$) HCHO-concentrations in a room can easily reach levels of 0.25 ppm, this is when for a typical spring or fall day the relative indoor humidity is 90 %, room temperature 20°C, GW = 3,5 and the load factor a = 1 $\frac{m^2}{m^3}$.

Because of this fact in further investigations of average German houses techniques of following the dominant regime will be developed.

If ventilation rates are lower, the indoor humidity and HCHO-concentration increase. A considerable amount of e.g. HCHO can be adsorbed by carpets, drapes, furnitures etc. (Seifert[13]) but it should not be an objective of energy saving to include desorption processes in strategies and that the built up concentrations are put down when people enter the room. At this time it is also not known, how short peaks in relative humidity due to adsorption processes of moisture on walls influence the possibility of mould growth there. For this reason all considerations introduced here do not account for these effects. They also do not account for non-perfect ventilation efficiency; it is always assumed that gases are completely mixed.

The amount of ACR necessary to avoid mould growth on one hand and to keep indoor air concentration of HCHO under a certain level behave contrarily. If indoor temperature is high the ACR to draw off the indoor generated moisture can be kept down where as the ACR to draw off the released HCHO must increase. Both calculated ACRs vary very much dependent on indoor temperature and humidity, amount of released moisture, load factor of particle board and acceptable indoor concentrations.

The quality of the wall insulation has a major impact on the calculated air flow rates necessary to remove moisture. Better insulated houses have higher interior surface-wall temperatures so that indoor air humidity can be higher and ACR lower.

2.1.4 Radon

A third influence factor on iaq which is independent of the occupancy of a room is radon. Radon-222 and Radon-220 is produced by the radioactive decay of Radium-226 and Thorium-232 nuclides.

The Radon-220 isotope has a halflife of only 54.5 seconds, whereas the Radon-222 has one of 3.8 days (Ericson et al 5)). It can partly move from the building material or the soil adjacent to the building and mix with indoor air. The inhaled radioactive noble gases are of minor importance for the radiation dose of people, as they are inert and don't stay in the respiratory tract. Of importance are their radioactive decay products like polonium, bismuth, and lead. Attached to airborne aerosoles they enter the respiratory system and contribute to the radiation exposure of the lung.

Ericson[6] reported mean indoor radon concentrations of 17 Bq/m³ for the building stock of the Federal Republic of Germany, newer investigations published by Keller[11] show mean values of 20-70 Bq/m³. This shows a great increase up to a factor of 4 as it was also realized in Sweden. These two figures may not be compatible as they do not cover the same area and houses and there is no information about ventilation rates in the monitored houses.

However, high ventilation rates should not be applied to reduce indoor radon concentration. Radon emissions should be minimized through restrictions for building material. It doesn't seem to be appropriate to introduce the radon concentration as a control parameter for ventilation.

2.1.5 Other Components

It seems to be appropriate to look only at pollutants, to which occupants are exposed over a long term. E.g. odours from fresh paint or the exposure to a casually applied insecticide may lead to short term increased ventilation and will be excluded in further considerations. Incoming contaminants from outdoor air can only be handled through special devices (e.g. filters) and are excluded too.

In conclusion, the above stated considerations show, that a basic ventilation is required. The necessary level could be discussed e.g. by statistical means and standards of german housing stock. As control parameter for basic ventilation rate one must check, if moisture or HCHO-production is predominant.

2.2 Occupied houses

Most contaminants of indoor air are caused by humans and their activities.

2.2.1 Moisture production

In occupied rooms we have additional moisture emission by humans themselves, by cooking, washing, showering, intake of wet clothes, etc.

Based on figure 1 with a mean outside humidity figure 4 enables - with indoor temperature and moisture emission as parameter - the determination of hourly ACRs to remove moisture.

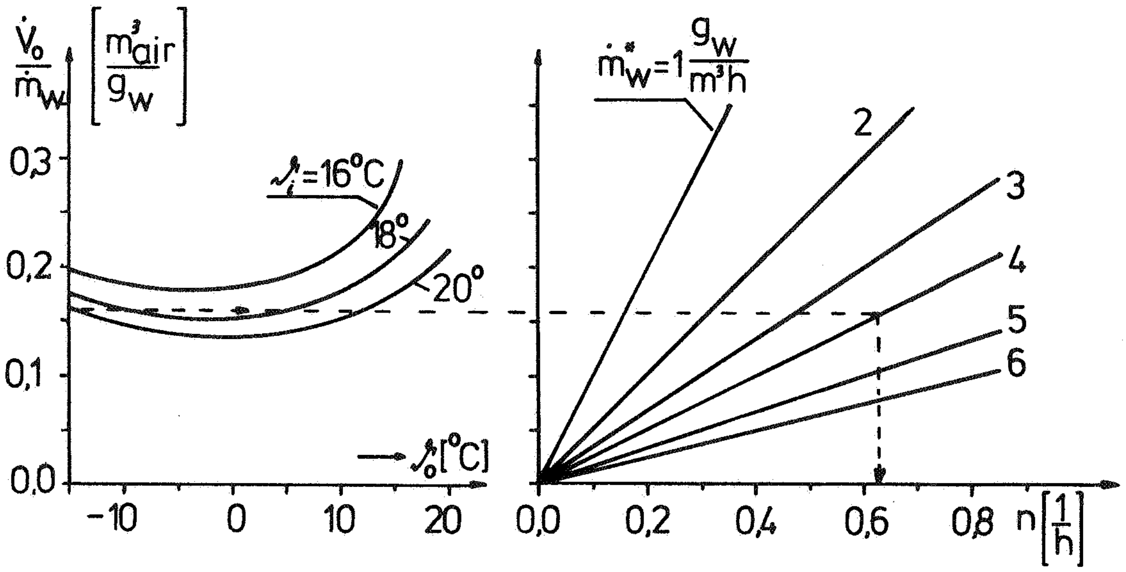

Fig. 4: Nomogram to obtain the hourly air change rate to remove moisture as a function of the source strength of water

For an average living room of 60 m³ and an occupancy of 3 persons with an evaporation of 4 $\frac{g}{hm^3_{\text{room}}}$ water and outdoor temperatures below +10°C we see that an hourly ACR of $n = 0{,}63\ \frac{1}{h}$ is necessary, when no condensation at surfaces and adsorption effects should occur and no other water vapor sources are present.

2.2.2 Carbon dioxyde (CO_2) and body odour

According to Tamura[14] the CO_2 output for an average sedentary adult is 18 $\frac{1}{h}$. The necessary ACR to keep the CO_2 concentration below a certain level is calculated by

$$n_{CO_2} = \frac{\dot{V}_{CO_2}}{V_R \cdot (c_i - c_o)} \cdot 10^3$$

Respiration problems of persons were first observed at 10.000 ppm CO_2 in the air. These high levels are usually not reached in a room.

However, studies of Berg-Munch et al[1] indicate that carbon dioxide can be well correlated with the intensity of body odour. The therefore proposed limits of CO_2 in rooms for European countries range from 1000 to 1500 ppm. For the reason of keeping a room odour-free CO_2 seems to be a suitable control parameter.

To keep CO_2 concentrations below 1500 ppm the necessary ACR versus CO_2-output with room volume as parameter is shown in Fig. 5.

For commonly occupied dwellings these ACRs are lower or in the range of the basic ventilation rates. From the point of view of a health risk CO_2 is not an appropriate control parameter.

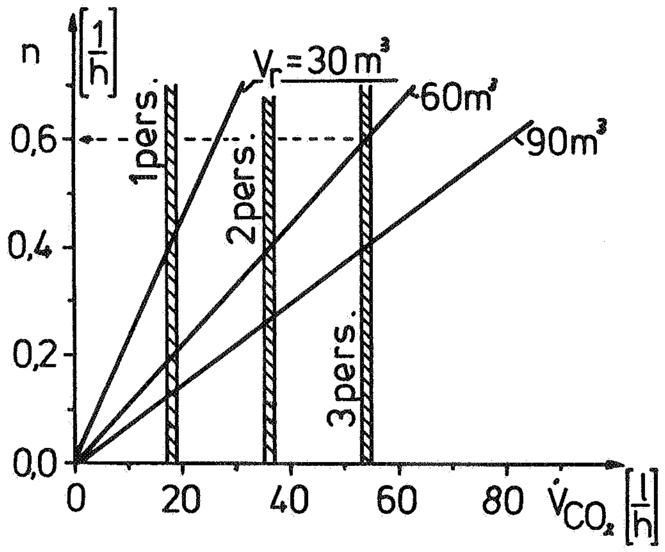

Fig. 5: Hourly air change rate necessary to keep indoor room concentration of CO_2 below 1500 ppm (outdoor concentration of CO_2 = 0)

As $C0_2$ and water-vapor output by humans is linked one can check which factor is dominant. Keeping the previous example of a living room with 3 occupants in mind, figure 4 gave a minimum hourly ACR of 0.63 $\frac{1}{h}$ for the removal of moisture. These 3 persons have a CO_2-output of 54 $\frac{1}{h}$. According to figure 5 an hourly ACR of 0.6 $\frac{1}{m}$ is necessary to keep the CO_2 level below 1500 ppm. For outdoor temperatures between 10÷15°C or lower indoor temperatures the ACR to remove moisture is higher and the CO_2 concentration is in the proposed range or even below 1000 ppm. This shows that if a room is adequately ventilated based on moisture control, there will usually be no problems with body odour.

These considerations may not be appropriate for schools, theatres or assembly halls, where CO_2 production may overshoot the production of moisture.

2.2.3 Tobacco smoke

Tobacco smoke is very annoying to many persons and it often decreases iaq to a non-acceptable limit. According to Wanner[15] tobacco smoke consists of a complex mixture of several thousand chemical compounds; carbon monoxide, nicotine, particulate matter, tar or condensate are the dominant one's. Wanner found that an air flow of 33 m^3/h is necessary in order to keep carbon monoxide (CO) concentrations below a proposed maximum allowable level of 2 ppm. An indoor air concentration of only 1 ppm CO (air flow rate of 66 m^3/h per person and cigarette) is needed to avoid eye irritation. Therefore, if smokers are present in a room, much higher ventilation rates are needed. CO may be an acceptable monitoring parameter for tobacco smoke. Also particulates or other substances have been discussed as control parameter for tobacco smoke. The recommendations are in the order of 70 m^3/h per person, sometimes even total separation of smoking and non-smoking areas is recommended.

In conclusion:

- for non-occupied rooms moisture and HCHO can be of a critical magnitude and either one of them can be dominant for the amount of basic ACR needed

- for occupied rooms the moisture release is dominant. Body odour should not be a major problem, when ACR are high enough to remove moisture. If smokers are present ventilation rates have to be much higher.

3. STATE OF THE ART AND VENTILATION STRATEGIES

The requirements to a ventilation system are primarily set up by achieving and maintaining good iaq. The ventilation rates necessary depend on outdoor conditions (weather, air pollution) inside conditions (persons, their activity, furniture, sort of room, etc.). From IEAs Annex IX "Minimum Ventilation Rates" we know the outdoor air supply needed for comfort and appropriate iaq. A first step to energy conservation is to hold ventilation rates on levels needed for health and comfort reasons. In practice this means to realize demand controlled ventilation. A further step is heat recovery.

Ventilation is up to now in the Federal Republic of Germany mostly realized by

- natural ventilation, in newer houses also by
- simple ventilation devices, and only to some extent by
- exhaust, supply or balanced ventilation systems,

Here we will only discuss the first two techniques briefly.

3.1 Natural ventilation

Natural ventilation is strongly influenced by wind and temperature differences between indoor and outdoor. As the wind blows arbitrarily its impact is very unpleasant and difficult to avoid in natural ventilated houses.

According to figure 1, there is only a much smaller amount of air flow needed, when the difference between indoor and outdoor temperature is high (winter time); but especially during that time thermal effects on natural ventilation systems are highest, i.e. outdoor temperature effects a natural ventilation system contrarily. If one wants to ensure the removal of moisture with a natural ventilation system, air change rates are either too low or too high. With common building design, where ventilation is achieved by infiltration through gap leakages, cracks in the building envelope or opening of windows, no acceptable iaq and a simultaneous energy efficient ventilation system can be realized.

Although natural ventilation remains the cheapest way to ventilate a building one has to check how higher ACRs effect the increase in energy costs and well-being of occupants.

3.2 Simple devices

If the lay-out of purpose provided openings in the building envelope is done in the way to meet basic ventilation needs during the wintertime for a mean wind speed and temp. difference, when the smallest ventilation rate is needed, one can think about simple devices, controlled by the user or temperature to increase ventilation during other times of the year (controllable slot vents in windows, levers to adjust the opening area of windows, stacks).

The advantage of these simple passive devices is an usually low price and the possibility for the user to interfer. As a human being is not sensitive to the relative humidity, it will happen that the ventilation rate must be greater than the occupant thinks.

The interference of the user is needed and well desired especially to increase ventilation in case of smoking. For the removal of moisture the system should act by itself.

A promising work is reported from Johnson et al 10), who tested passive ventilation systems with especially developed devices in some houses of the UK. Their systems consisted of controllable slot vents in all windows and exhaust tubes in the bath and kitchen.

Similar tests have been performed in Sweden by Eriksson et al[7)], who used temperature controlled slot vents in windows. The recent results are very promising and encouraging for the future work in this field.

4. CONCLUSIONS

To maintain an acceptable iaq and to operate an energy efficient ventilation system it is advisable to supply a room with a basic air flow rate when it is not occupied and add an additional flow rate, when occupants are present. At the present situation of insulation and emission standards in the Federal Republic of Germany, evaporation of water and emission of HCHO in non-occupied rooms can be dominant depending on the sources, building insulation and season. The amount of the additional ventilation rate depends mainly on the source strength of water vapor in the room. A humidity sensor may be a good way to ensure good iaq. In rooms with smokers the necessary ventilation rates have to be much higher to avoid annoyance caused by smoke. A CO sensors is appropriate to control ventilation rates if smokes are present. Most houses in the Federal Republic of Germany are ventilated by natural ventilation which doesn't fulfill the requirements to iaq and energy savings. There has been much encouraging progress in achieving good results with simple ventilation devices. This should be the objectives in further r and d projects.

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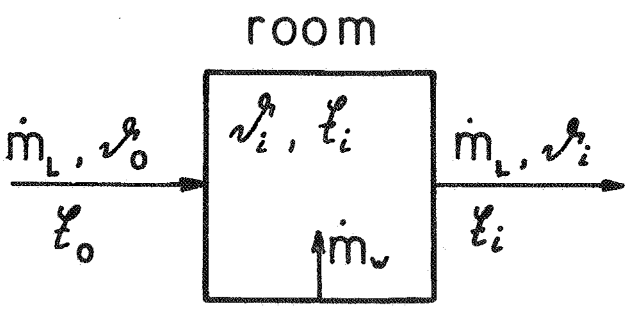
Appendix I:

For steady state conditions, no absorption or desorption effects, and no condensation at window glasses, the continuity equation applied to a room with indoor water vapor sources and in- and outgoing air is



$$\dot{m}_L \cdot X_o + \dot{m}_w = \dot{m}_L \cdot X_i$$

$\dot{m}_L$ = mass flow rate of dry air $[\frac{kg}{s}]$

X_o = water content of outdoor air $[\frac{kg_{water}}{kg_{dry\ air}}]$

X_i = water content of indoor air $[\frac{kg_{water}}{kg_{dry\ air}}]$

$\dot{m}_w$ = indoor generated water vapor flow rate $[\frac{kg}{s}]$

φ_o = rel. humidity outdoor [-]

φ_i = rel. humidity indoor [-]

ϑ_o = temperature outdoor [°C]

ϑ_i = temperature indoor [°C]

T_o = temperature outdoor [K]

T_i = temperature indoor [K]

$$\dot{m}_L = \frac{\dot{m}_w}{X_i - X_o} \qquad (1)$$

with eqn. 1 and ideal gas law applied to a mixture of dry air and water vapor, the outgoing volume flow rate $\dot{V}_o$ is given by

$$\frac{\dot{V}_o}{\dot{m}_w} = \frac{1}{X_i - X_o} \cdot \frac{R_w \cdot T_i}{p} \left(\frac{M_w}{M_L} + X_i\right) \qquad (2)$$

where $R_w = 461 \left[\frac{J}{kg\ K}\right]$ is the gas constant of water vapor

$p = 10^5$ [Pa] is the ambient pressure

and $\frac{M_w}{M_L} = 0{,}622$ mole ratio of water and air

The maximum rel. indoor air humidity is calculated so that no condensation occurs on the coldest interior surfaces of the walls. These are usually the exterior walls. The lowest surface temperature of a wall which meet the FRG insulation standard DIN 4108 are to be found in 2- or 3-dimensional corners. According to Erhorn et al4), the surface temperature ϑ_i^s can be estimated by

$$\vartheta_i^s = \vartheta_o + 0{,}63 \cdot (\vartheta_i - \vartheta_o) \qquad (3)$$

from this the water content X_i is calculated by

$$X_i = \frac{p_s(\vartheta_i^s)}{\frac{p}{\varphi_i^s} - p_s(\vartheta_i^s)} \cdot \frac{M_w}{M_L} \qquad (4)$$

p_s = saturation vapor pressure of water [Pa]

φ_i^s = rel. humidity at the surface of the wall ≤ 1.0

Transforming eqn. (4) we get the expression for the maximum rel. humidity inside the room to

$$\varphi_i = \frac{p}{\frac{p_s(\vartheta_i)}{X_i} \cdot \frac{M_w}{M_L} + p_s(\vartheta_i)} \qquad (5)$$

The water content of the outdoor air is analogous to eqn. (4)

$$x_o = \frac{p_s(\vartheta_o)}{\frac{p}{\varphi_o} - p_s(\vartheta_o)} \cdot \frac{M_W}{M_L} \tag{6}$$

According to DIN 4710 the variation of outdoor humidity as a function of outdoor temperature gives table 2.

ϑ_o [°C]	-10°	0°	10°	20°
φ_o [-]	0,65-0,95	0,68-0,88	0,70-0,83	0,71-0,8

Tab. 2: Range of rel. outdoor humidity as a function of outdoor temperature for 13 locations spread over the FRG according to DIN 4710

With input parameters ϑ_o, φ_o, ϑ_i eqn. (2) can be calculated. A plot of $\frac{\dot{V}_o}{\dot{m}_W}$ versus ϑ_o with parameter ϑ_i shows figure 1.

Appendix II:

According to Mehlhorn12) the equation to determine the HCHO concentration in a ventilated room is given by

$$c = \frac{4.37 \cdot 10^{-5} \cdot (GW - 0{,}046)\ (\vartheta_i - 6{,}07) \cdot (\varphi_i + 32{,}3)}{1 + \frac{n}{a} \cdot 0{,}968}$$

c = HCHO concentration [ppm]

GW = material constant ($<$ 3,5 for particle board FRG emission class E1)

φ_i = rel. humidity in %

n = hourly ACR $[\frac{1}{h}]$

a = load factor $[\frac{m^2}{m^3}]$

validity range:

temperature	$15° < \vartheta_i < 30°C$
rel. humidity	$26 < \varphi_i < 82$ %
hourly air change rate	$0{,}4 < n < 3{,}0\ \frac{1}{h}$
load factor	$0{,}2 < a < 1{,}16\ \frac{m^2}{m^3}$

Comment: As rel. humidities in a room can be higher than 82 % at outdoor temperatures of 15°C, the bar for HCHO in figure 3a and 3b of ϑ_o = 15°C is calculated by extrapolating the above formula to higher rel. humidities, which may cause uncertainties.