Ventilation Requirements to Prevent Surface Condensation. Case Study for a Three-Person Dwelling

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Background

While the choice of reduction of transmission losses of a building to very low values is more or less only a question of economics, minimizing ventilation to reduce the heat loss may produce a lot of problems regarding air quality and building physics. This problem has not only been experienced in a great number of buildings in Germany, but it is also a problem common to all IEA member countries.

Ventilation in buildings is required for a number of reasons. These include the need to:

- substitute oxygen consumed by people and flueless fireplaces
- supply combustion air to open-flued combustion appliances
- remove water vapour produced by washing and cooking activities, by people and plants
- remove hazardous pollutants originating from building materials, furnishings, tobacco smoke and the countless household chemicals in use today
- remove odours.

In practice it seems appropriate to consider ventilation requirements under three separate risk aspects. These are:

1. Removal of pollutants harmful to health.
2. Avoiding building damage by moisture.
3. Safe operation of stoves and fireplaces.

Ventilation should be provided in such a way and to such an extent that all three requirements are met. This paper deals with the second aspect, namely that of moisture.

Ventilation efficiency

Ventilation is an extremely complex phenomenon. With an open window for instance, variations in wind and outside temperature have a strong influence on the rate of air change. But even setting aside such variations, an open window will neither provide for complete mixing of room air, nor will it provide perfect displacement ventilation thus the ventilation efficiency is uncertain.

Ventilation efficiency expresses the ability of a system at a given volume flow rate to dilute or to remove pollutants from specified zones such as occupied areas or cold surfaces, i.e. ventilation efficiency may be defined as[1]:

$$e = \frac{Cx - Co}{CRi - Co}$$

where Cx = pollution concentration in the exhaust air

Co = pollution concentration in the supply (outside) air

CRi = pollution concentration in the room air at location i.

When Cx = CRi, complete mixing occurs, i.e. e = 1 (dilution ventilation). Such a condition may hardly be found in practice but is most commonly assumed for calculation and modelling purposes. The main reason for using this assumption is to account for the complex pattern of air movement in a room.

If not otherwise specified, the air change rate in this paper refers to complete mixing. In many practical cases, special provisions, e.g. range hoods, or users' behaviour, e.g. opening of windows close to the pollution source, will improve vapour removal ($e > 1$); in some other cases it may reduce it, e.g. in 'dead' corners of a room, $e < 1$. In general, however, the air exchange rate referred to by complete mixing is a good average estimation and may, in most cases, be assumed to be on the safe side of the real ventilation efficiency.

Relevant to surface condensation is the dew point of the air in the vicinity of cold surfaces, *not* the average water content of the room air. This is a point of particular relevance for the planning and installation of efficient ventilation systems.

Production rates of water vapour in dwellings

In contrast to the situation with chemical pollutants, the potential emission sources of water vapour are known. Even though users' behaviour varies in a broad band, the expected range can be estimated.

The following 'model dwelling' will be investigated:

apartment
100 m² living area
three person family
average factor of presence: 0.7

A number of publications[2,3,4,5,6] specify vapour production rates of sources commonly found in dwellings. Table 1 lists the main sources and their emission rates.

Person asleep	40 g/h
Person average activity	90 g/h
Potted plant, average size	10 g/h
Cooking and wet cleaning	1,000 g/h
Taking shower	2,600 g/h
Washing machine	300 g/cycle
Free water surfaces	200 g/hm²

Table 1. Sources of Water Vapour in Dwellings

By using these rates in conjunction with the data of the model dwelling, a vapour load as specified in Table 2 results. The total moisture generation rate is about 12 kg per day or, on average, 500g per hour.

As already mentioned, the amount of water vapour actually remaining in the air can be expected to be considerably lower than the values listed because part of the vapour generated by particularly critical processes, e.g. cooking, showers, is normally removed by direct ventilation before mixing with the room air. Additional loads would be added if washing were to be dried in the rooms. However, such drying cannot be considered usual and is normally prohibited by contract. Also, because of the water storage capability of building materials, peak loads of vapour do not generally pose a problem.

24 person hours asleep	960 g/d
27 person hours average activity	2,430 g/d
15 potted plants	3,600 g/d
3 hours cooking/wet cleaning	3,000 g/d
5 cycles washing machine	150 g/d
15 minutes shower	650 g/d
1,000 cm^2 free water surfaces	480 g/d
Additional contributions (rain-wet cloth ...)	200 g/d
TOTAL	11,470 g/d

Table 2. Water Vapour Production in a 3-Person Dwelling

Critical building surfaces

The cold outer surfaces of a building are the critical ones producing condensation problems. Gertis[5] has investigated the thermal behaviour of particularly critical building geometries. In a three-dimensional corner in the outside walls of a building under a flat roof ceiling (one of the geometries bearing the highest condensation risk), constructed according to the German building standards of 1981, it was found that the surface temperature will fall below the room temperature by about one third of the difference between room temperature and outside temperature. If, for example, the outside temperature is 2°C and the inside temperature is 20°C, a corner temperature of only 14°C will result. According to the same source, the temperature drop in one-dimensional corners of older buildings (flat roofs are seldom encountered with them) is of the same order.

Minimum ventilation rate for dehumidification

From the point-of-view of avoiding surface condensation, the ventilation requirement is given by:

> the air change rate that results in the vapour content of the room air in the vicinity of cold surfaces being such that the dew point temperature is below the lowest surface temperature.

Examples of some calculations of minimum ventilation rates to avoid condensation for some typical meteorological situations are given in Table 3. The results presented are for:

- a cold winter day
- an average winter day
- a typical spring or autumn day
- a day on which the outside temperature is just above that at which space heating is required.

In all cases, relative humidity of the outside air is assumed to be 80%, since this value is not exceeded under average German meteorological conditions. The surface temperatures according to Gertis[5] are used for determination of the maximum allowed water content of the room air. As can be seen from the fifth row of Table 3, the maximum admissible humidity is lower during colder days, because of the lower building surface temperature then. Taking into account the vapour production in the dwelling, the necessary air exchange rate can be determined.

It is seen from Table 3 that, for all temperatures during the heating season, an air exchange rate of $\dot{V}_{min} = 85\ m^3/h$ is sufficient in the model dwelling, corresponding to 0.34 air changes per hour. Even in a considerably smaller dwelling of, for example, 70 m^2 living area and with the same vapour load, the generally recommended air change rate of 0.5 ach can be considered sufficient. Generally, the use of volume flow rates (e.g. m^3/h) rather than air change rates referred to the dwelling's volume (1/h) should be used when specifying dehumidification requirements.

	Symbol	Cold winter day	Average winter day	Transitional season	Day at heating limit
Outside temp.	To	–4°C	5°C	11°C	14°C
Relative humidity of outside air	φo	80%	80%	80%	80%
Room temp.	Tr	20°C	20°C	20°C	20°C
Temp. at critical building surfaces[5]	Ts	12°C	15°C	17°C	18°C
Admissible room air humidity so that no condensation takes place at Ts	φadm	60%	73%	82%	88%
Vapour absorption capacity of the outside air after being heated to Tr	Δx	6.5 g/kg	6.4 g/kg	5.6 g/kg	4.9 g/k
Daily vapour production in the 3-person dwelling	$\dot{m}_{H2O}$	12 kg/d	12 kg/d	12 kg/d	12 kg/d
Minimum ventilation rate for dehumidification	$\dot{V}$min	64 m^3/h	65 m^3/h	75 m^3/h	85 m^3/h

Table 3. Dehumidification by Ventilation in a 3-Person dwelling

With rising outside temperature, the minimum required air change also rises. It is therefore important to increase ventilation beyond the specified value *outside* the heating season. This is less of a problem with regard to economy or comfort because no energy losses are taking place and because draught effects play only a minor role during the warm season. However, deliberate measures to increase ventilation are necessary since the thermal forces driving ventilation are weak or absent. Experience shows that these are the conditions at which condensation problems are encountered, particularly during the transitional season. However, there is no public awareness of this problem.

Discussion of the results

The case presented can be expected to be representative for a great number of dwellings in the existing building stock. In new buildings with improved insulation, which conform to the latest regulations, lower air change rates during the colder season only are permissible. At higher outside temperatures, during the particularly critical transitional period, differences between ventilation requirements for old and new buildings are negligible.

That the specified air change rate is indeed sufficient under normal conditions is confirmed by the observation that in many dwellings air change rates under 0.5 are taking place. Nevertheless, condensation problems occur only then if additional stress factors deteriorate the situation such as:

- additional vapour generation, e.g. drying of washing in dwellings
- use of air humidifiers
- considerable reduction of room temperature, e.g. in bedrooms
- deterioration of the heat transfer coefficient from the room air to critical (cold) building surfaces, e.g. furniture positioned against outside walls
- hydraulic isolation of wet rooms from the remainder of the dwelling (closed windows and internal doors).

It should be noticed that this paper considers only surface condensation. With building envelopes of deficient construction, e.g. vapour barrier wrongly placed condensation may occur inside a building element thereby impairing its function and durability.

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