# INFLUENCE OF THE MODE OF VENTILATION ON HEAT LOSSES FROM BUILDINGS DUE TO VENTILATION

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In recent years, heat insulation of buildings has been improved progressively. This has led to a reduction in transmission heat losses from buildings. On the other hand, heat losses due to ventilation have not been reduced to the same extent and their share of the total heat consumption of a building has accordingly increased. Heat losses due to ventilation may nowadays account for 50% or even more of the total loss of heat, and they assume thus an ever increasing importance.

Since it is not possible to eliminate loss of heat due to ventilation altogether (a certain amount of outside air must be supplied while a room is in use, on the grounds of hygiene and health), special attention must be paid to application of the correct form of intermittent or continuous ventilation. The author, therefore, discusses the influence of the form of ventilation on the energy balance in buildings, choosing a natural form of ventilation of rooms via the windows or other openings as the basis of the arguments.

## Intermittent and continuous ventilation

The energy balance of a building is the result of the interaction with the building of a variety of factors such as solar radiation, outside temperature and the effect of users. Since these factors may be subject to both daily and long-term variations, the heat and energy balance of a building is not constant.

To establish the influence of the form of ventilation by itself, constant outside temperatures and negligible solar radiation intensities are assumed. Under these conditions, continuous ventilation gives rise to steady temperature relationships. The temperature of the air inside the rooms then remains constant throughout the day as does the amount of heat required to maintain it at this level. For such a system, the loss of heat due to ventilation can be determined relatively easily.

With intermittent ventilation, different relationships obtain, since this form of ventilation being unsteady in itself, sets up unsteady conditions. Neither the temperature of the air in the rooms nor the amount of heat to be supplied remains constant. To illustrate processes taking place with intermittent ventilation, Fig. 1 gives a schematic representation of the factors involved. In intermittent ventilation there is a sudden increase in the number of air changes, mostly over a short period of time, as can be seen from the topmost diagram. In this example, air is changed at a rate of 5 $h^{-1}$ between 12 a.m. and 1 p.m. During the remainder of the time there is only basic ventilation with an air change rate of 0.8 $h^{-1}$.

During intermittent ventilation, the temperature of the inside air falls, assuming the heat input to remain constant. From the point of view of energy consumption, an inertialess heating system in which the heat input falls to zero during intermittent ventilation, is to be preferred. In practice, however, it is conceivable that the heat input might increase as a result of the cooler outside air streaming in, so that the assumption of an unchanged heat input, made above, seems to be most appropriate to these conditions.

After the ventilation cycle has been stopped, the heat input must increase to raise the room temperature once more to the set value (22°C in the present example). As soon as this has been attained, the heat input can be reduced again. In diagrams relating to conditions of continuous ventilation, a horizontal straight line would be obtained in all cases. The constant number of air changes would result in a constant room temperature and hence a constant heat input.

The bottom diagram of Fig. 1 shows the carbon dioxide concentration in the air in the room. This serves as an air quality indicator, because in man, there is a correlation between the output of $CO_2$ and the formation of odorous substances, and since an increase in the $CO_2$-concentration leads to a reduction in the transport of oxygen in the blood[1]. The acceptable limit for this concentration is generally taken to be the so-called Pettenkofer limit at 0.1 vol.%. In Fig. 1, the $CO_2$-concentration in the outside air is given as 0.03 vol. %, a value generally accepted for the open countryside. In cities, values of 0.05 vol. % have been measured and in conurbations even 0.08 vol. %[2-6].

Under conditions of continuous ventilation and with a constant $CO_2$ output, we would have a constant $CO_2$-concentration in the inside air; at high basic ventilation this would lie in the lower part of the diagram and with low ventilation in its upper portion. On the other hand, with intermittent ventilation, the $CO_2$ concentration decreases during ventilation periods and then rises again.

On completion of one ventilation period the $CO_2$ concentration need not have fallen to that of the outside air, although, as in the case illustrated here, there was an air change at a rate of 5 $h^{-1}$, i.e. the air in the room was renewed 5 times. This is due to the mode in which exchange between 'fresh' and 'used' air takes place. In principle, three different cases may be imagined, as described elsewhere[7]. When ventilation is via the windows, the exchange of warm, used air from the room against cold fresh outside air is best described as a convective air exchange in which complete mixing of inside and outside air takes place. For any given case, the $CO_2$ concentration is obtained from the balance of the volume of air in the room, using the following equations:

$$\dot{V}_{ZL}\, c_{ZL} + \dot{V}_{CO_2} = \frac{V_R\, dc_R}{dt} - \dot{V}_{AL}\, c_{AL} \qquad (1)$$

where

$\dot{V}_{ZL}$ is the volume of (fresh) air supplied ($m^3/h$),

$\dot{V}_{AL}$ the volume of (used) air discharged from the room ($m^3/h$),

$V_R$ the volume of the room ($m^3$)

$\dot{V}_{CO_2}$ $CO_2$ output in the room ($m^3h$)

$c_{ZL}$ $CO_2$ concentration in the fresh air (vol. %),

$c_{AL}$ $CO_2$ concentration of the discharged air (vol. %),

$c_R$ $CO_2$ concentration in the air in the room (vol. %),

t the time (h).

Applying the continuity equation and the number of air changes (n), given by

$$\dot{V}_{ZL} = \dot{V}_{AL} = \dot{V}_L \qquad (2)$$

$$n = \frac{\dot{V}_L}{V_R} \qquad (3)$$

we obtain, assuming $C_{AL} = C_R$, as stated above, the following differential equation:

$$- \frac{\dot{V}_{CO_2}}{V_R} = 0 \qquad (4)$$

If the $CO_2$ concentration in the air in the room at the time t = 0 is $C_{R_0}$, we obtain the following solution:

$$c_R(t) = c_{ZL} + \frac{\dot{V}_{CO_2}}{n \cdot V_R} + \left( c_{R0} - c_{ZL} - \frac{\dot{V}_{CO_2}}{n \cdot V_R} \right) e^{-nt} \qquad (5)$$

The temperature of the air in the room can also be found by deriving the balance for the volume of air in the room, but including in this case the time-dependent temperatures of the surfaces enclosing the room. A detailed derivation and description of this balance and its solution are given in paper[8].

To represent the influence of the type of ventilation on the energy behaviour of a building, we shall examine below two variants of intermittent ventilation and compare these with a continuous ventilation method. The comparison between the different forms of ventilation with regard to heating energy losses, is initially based on the assumption that the same volume of air is changed, in one day, in all cases. Fig. 2 shows the variations in the number of air changes in one day.

An examination of the heat outputs corresponding to these variations in the number of air changes, given in Fig. 3, shows, as stated above, that the heat output is constant under conditions of continuous ventilation, although the generation of physiological heat by the users of the room during its occupation can of course be deducted. The construction of the building (heavy or light) introduces a difference since different types of outer walls possess different heat transition coefficients. In addition it is seen that intermittent ventilation gives rise to considerable unsteady heat inputs. A large number of individual ventilating operations also produces numerous heat input peaks and in this connection, buildings of lighter design produce greater fluctuations in the heat input than those of a heavier type since the former cool off to a somewhat greater degree and then correspondingly require more heat to bring them up to the required temperature level. The area underneath the heat input curves is a measure for the consumption of heating energy. At first glance, it is difficult to discern a difference between continuous and intermittent ventilation in this respect. For this reason, Fig. 4 provides a direct comparison of the consumption of heat incurred using the two modes of ventilation, differentiating between buildings of heavy and light design.

Using continuous ventilation as reference, putting the value obtained for this as equal to 100%, we obtain for the loss of heat due to ventilation values of 98.3 and 97.4% for the first variant of intermittent ventilation and 96.8 and 94.8% for the second variant.
In a separate study[7)] we compared further variants of intermittent ventilation with the corresponding continuous mode of ventilation and obtained analogous tendencies. If a heating system capable of perfect control is available, a small energy saving can be achieved with intermittent ventilation, as a result of the temperature drop during ventilation periods. As is to be expected, greater savings result in buildings of light construction than in those of heavy construction, on account of the lower heat storage capacity of the former. In addition it is found that an increase in the number of ventilating periods increases the consumption of heating energy in spite of an appropriate reduction in the length of the individual period.

A reduction of the volume of basic ventilation, as close as possible to 0 changes of air/h, would lead to a substantial decrease in heat losses due to ventilation in intermittent ventilation, but unfortunately it is not likely that this can be achieved with windows of the type in current use.

Ventilation serves to ensure that the air in the rooms is of good quality. It is, therefore, necessary when making comparisons of intermittent and continuous ventilation to include the relevant $CO_2$ concentrations in the air in the room. For this reason, Fig. 5 shows the course of this concentration during one day, as derived from the ventilating habits illustrated in Fig. 2. The room in question is occupied by one person during the period of 6 a.m. to 6 p.m.

Irrespective of the mode of ventilation used, there is a steep increase in the $CO_2$ concentration as soon as the room is occupied. In the case of continuous ventilation it remains at a constant level as long as the room continues to be in use and then drops to the value of the outside air. On the other hand, with intermittent ventilation, the above-mentioned jumps in concentration take place. During the ventilating period the $CO_2$ concentration drops rapidly and then rises again fairly quickly. The mean $CO_2$ concentration observed with intermittent ventilation is slightly lower than that resulting from continuous ventilation, at least with the first intermittent variant. On the other hand, intermittent ventilation leads to slightly higher peak values; in fact the second intermittent variant gives peak values which lie slightly above the Pettenkofer limit.

If the maximum $CO_2$ concentration only is used as a measure for the quality of the air in the room, as was done by Wiedenhoff[9], it becomes possible to reduce somewhat the volume of air exchanged in continuous ventilation as compared with intermittent ventilation, until the same maximum $CO_2$ concentrations are obtained with both modes of ventilation. This would reduce the energy saving shown in Fig. 4; heat losses due to ventilation could then rise to above 100%, i.e. energy consumption under conditions of continuous ventilation would be lower than that under conditions of intermittent ventilation. However, if basic ventilation is stopped when the room in question is unoccupied, intermittent ventilation would lead to lower maximum $CO_2$ concentrations since it would then be possible to increase ventilation during the period of use while maintaining the volume of air exchanged at the same level. As a result of this, it would be possible, in contradiction to the conclusions drawn in paper[9], to achieve a saving of energy, in the first instance because of the unsteady effects and secondly because of the reduced amount of outside air required to ensure the same maximum $CO_2$ concentration as in continuous ventilation.

<u>How to ventilate? Which form of ventilation gives the most favourable results from the point of view of energy consumption?</u>

There should be no ventilation while rooms are not in use since no-one profits from the good quality of the air during such periods, unless a certain change of air is necessary on account of intensive production of steam or odorous substances or because of individual heating appliances used.

Depending on conditions, there should be instant continuous ventilation or a prolonged ventilation period while the room is in use to ensure that the $CO_2$ concentration in the air of the room does not rise above the Pettenkofer limit.

This is illustrated in Fig. 6. In the top diagram, the number of persons in occupation is plotted against the time. In this example, it is again assumed that the room is occupied by one person between 6 a.m. and 6 p.m. Ventilation must be such as to ensure that the Pettenkofer limit is not exceeded at any point of time. For the room under consideration in the present example, an air change of 0.88 $h^{-1}$ is required to achieve this while the room is being used. With smaller rooms this number is larger and with larger ones smaller. It is not the number of air changes which is decisive but the absolute volume of air changed. Thus, under the conditions outlined here, one person requires about 40 $m^3$ of (fresh) outside air per hour. In the room in question this corresponds to about 0.88 air changes per hour. While the room is unoccupied, ventilation could be dispensed with. This mode of ventilation would be adapted exactly to the needs of the user(s) and would thus constitute ventilation purely according to requirement.

This would make it possible to achieve very substantial energy savings. It would be possible to reduce heat losses due to ventilation to less than half the corresponding losses incurred with continuous ventilation, i.e. to 42.9%. Even greater reductions would be possible with shorter periods of use. When using this form of ventilation it would, however, be necessary for the air change to be governed by the $CO_2$ content of the air in the room in order to guarantee optimum results under conditions in which the number of persons present in the room varies. This cannot be achieved as yet, but should be kept in view, as a possibility for the future. More recent types of ventilation plants which produce an approximately constant change of air, independently of the dynamic pressure applied, can also lead to ventilation based purely on requirements, given sufficient experience of the user, provided the necessary steps are taken to ensure that there is no ventilation while the room is not in use (an extremely important point !). Windows the position of which can be finely adjusted (e.g. slanted) can also constitute a first step towards requirements-based ventilation, provided it is possible at the same time to awaken the understanding of the users for heat- and energy-technical requirements.

At all events, windows which can be shut tight when the room is not in use, are an essential prerequisite. While the room is occupied, the necessary air should be introduced in accordance with requirements. For this purpose, intermittent ventilation is to be preferred to continuous ventilation, since the latter generally results in unnecessarily high rates of air exchange with the minimum window openings (slanted position) attainable at present, which are bound up with greater ventilation heat losses.

The future should see a move towards ventilation in accordance with requirements by the design of appropriate windows and ventilating units, and hence to a drastic reduction in heat losses due to ventilation and in the total heating energy consumption.

References

1. K. Gertis et al., Problems of the ventilation of living spaces. Economising on energy, heat protection, air requirements, hygiene, individual heating units. VDI-Bericht, 1979 (317), 55 - 60.

2. Recknagel-Sprenger, Taschenbuch für Heizung und Klimatechnik (Pocket book of heating and air conditioning), 58th edition, Munich 1974, Publ. Oldenburg-Verlag.

3. W. Kreutz, The carbon dioxide content of the lower layers of air as a function of weathering factors. Angew. Botanik, 1941, 23, H. 89.

4. F. Steimle, Air-conditioning at the place of work. Report on the Egelsbach Conference. Supplement Ges.-Ing., 1976, 97 (9).

5. W. Müller-Limroth, General ventilation requirements for living accommodation based on hygienic, physiological and bacteriological factors. Unpublished evaluation (1977).

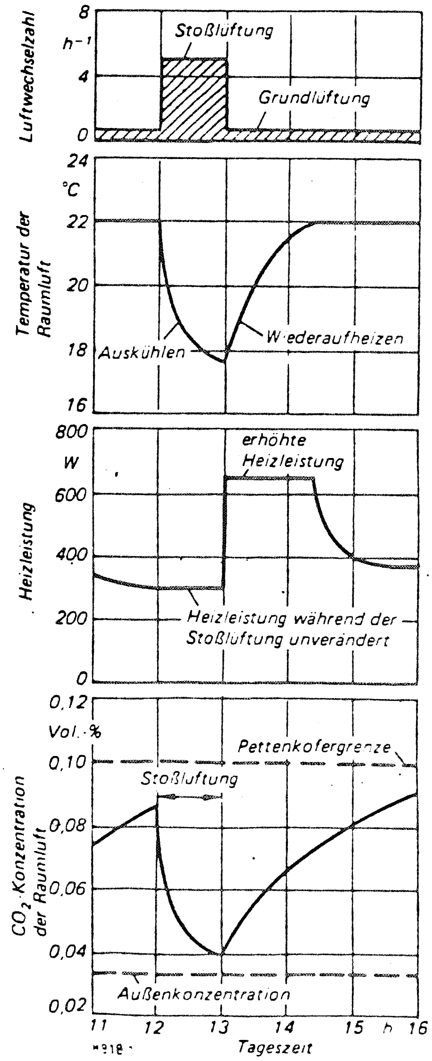
6. Battelle Institute, Investigation of the requirement of fresh air in living areas. Unpublished study (1977).

7. K. Gertis and G. Hauser, Energy saving by intermittent ventilation? this journal, 1979, 30 (3), 89-93.

8. G. Hauser, Forecasting of the heating behaviour of large buildings by calculation. Dissertation. University of Stuttgart (1977).

9. R. Wiedenhoff, Intermittent ventilation of living areas from the point of view of energy consumption. This journal, 1977, 28 (12), 439-444.

Fig. 1: Schematic representation of heating and ventilation technical processes occurring in intermittent ventilation.




Number of air changes

Intermittent ventilation

Basic ventilation

Air temperature in the room

Cooling

Reheating

Increased heat input

Heat input

Heat input remains unchanged during intermittent ventilation.

Pettenkofer limit

Intermittent ventilation

$CO_2$ concentration in the air in the room.

Concentration in outside air.

Time of day.

Fig. 2: Variations in the number of air changes during the day in continuous and intermittent ventilation forming the basis of this example.

In continuous ventilation the number of air changes was 1.0 $h^{-1}$ and with intermittent ventilation the basic ventilation was 0.8 $h^{-1}$, giving the same overall volume of air changed in one day in all cases.

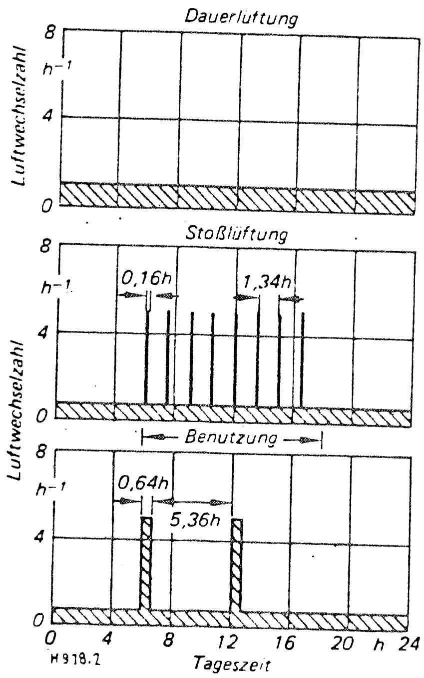
Continuous ventilation

Number of air changes

Intermittent ventilation

Number of air changes

In occupation




Time of day

Fig. 3: Variations during one day in the heat input in office rooms located in buildings of heavy or light construction under ventilating conditions illustrated in Fig. 2.

The room was occupied by one person during the period of 6 a.m. to 6 p.m. A detailed description of the mode of construction is given in paper [7].

Continuous ventilation

Heavy construction

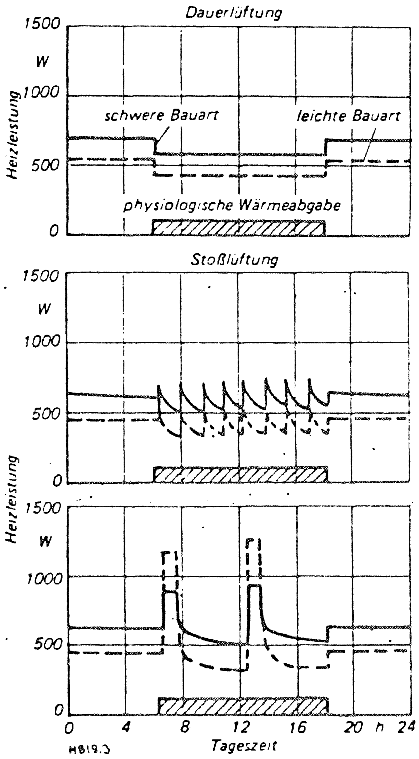
Heat input

light construction

Physiological heat output

Intermittent ventilation

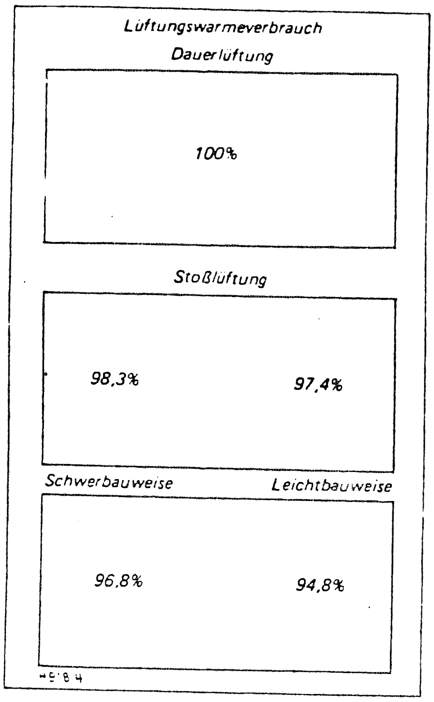
Heat input




Time of day

Fig. 4: Comparison of the heat consumption resulting from ventilation in the different modes of ventilation illustrated in Fig. 2.

Consumption of heat due to ventilation




Continuous ventilation

100%

Intermittent ventilation

98.3%

97.4%

Heavy construction

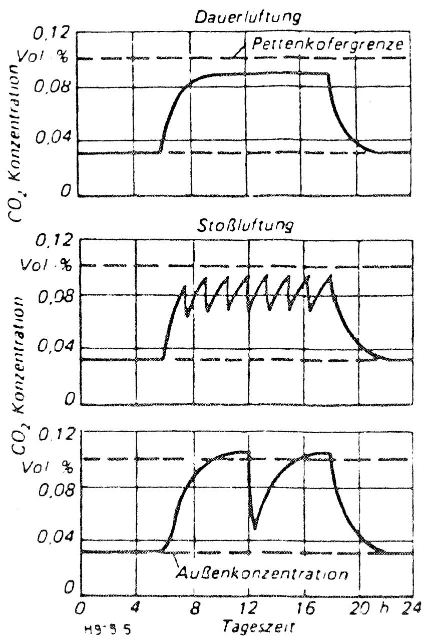
Light construction

96.8%

94.8%

Fig. 5: Variation during one day, of the $CO_2$ concentration in the room in the air with ventilation by the different modes illustrated in Fig. 2.

Continuous ventilation




Pettenkofer limit

$CO_2$ concentration

Intermittent ventilation

$CO_2$ concentration

$CO_2$ concentration in the outside air

Time of day

Fig. 6: Schematic representation of ventilation according to requirement.

Ventilation according to requirements

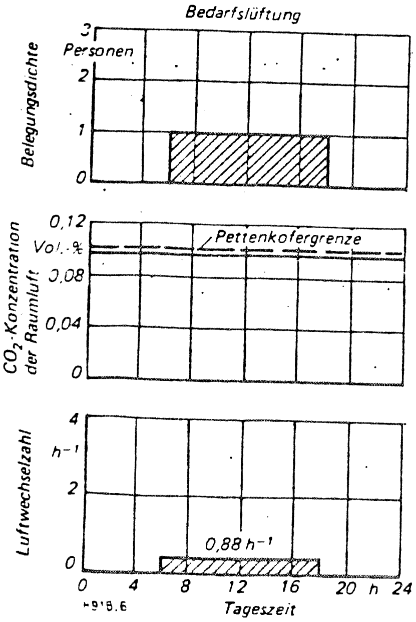
Persons

No. of persons occupying the room

Pettenkofer limit

$CO_2$ concentration in the air of the room

Number of air changes




Time of day