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On ventilation needs – towards demand controlled ventilation in dwellings

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ON VENTILATION NEEDS – TOWARDS DEMAND CONTROLLED VENTILATION IN DWELLINGS

SYNOPSIS
Ventilation needs in dwellings must be determined on the basis of both requirements to the indoor air quality and necessary control of moisture conditions. As a first step towards development of energy efficient ventilation strategies for demand controlled ventilation in future dwellings theoretical analyses comprising a literature study and mathematical simulations have been carried out. In view of the provisions in the current Danish Building Regulations and based on existing knowledge on contaminants and contaminant sources in the indoor climate, the humidity conditions are regarded as determining for the ventilation requirements in future dwellings. The mathematical simulations indicate that the basic ventilation in a typical apartment under normal use can be reduced by 20-30 percent compared with provisions in current building regulations without compromising the indoor climate. Thus, through a suitable control of the ventilation on average energy savings can be achieved on the energy consumption for ventilation in multi-storey buildings.

1. INTRODUCTION
In 1999 The Danish Building Research Institute initiated a major research programme in four phases on energy efficient demand controlled ventilation in dwellings. The overall aim of the research programme is to develop and test innovative and energy efficient ventilation strategies that are capable of providing a good indoor climate with least possible energy consumption for ventilation. Basically, the ventilation strategies will be founded on a general reduction of the continuous basic ventilation and possibilities for individual increase of the ventilation corresponding to the actual needs within each dwelling and room. The four phases of the programme are forming a joint effort that will provide the basis for development of new ventilation solutions and also form part of the considerations concerning amendments to the ventilation requirements in the Danish Building Regulations 2005. The four phases of the research programme are:

1) Evaluation of ventilation needs in dwellings and set up of a dynamic model for the moisture balance in the room air in dwellings in use
2) Development and testing in the lab of selected ventilation strategies
3) Full scale testing in demonstration buildings
4) Measurements and evaluations of the tests in the demonstration buildings

The first phase of the research programme has been completed and the present paper is summarising parts of the results focusing on the determination of the ventilation needs in future dwellings. Phase two will start off by mid 2000.

2. VENTILATION IN DWELLINGS

The main purpose of ventilating a dwelling is to satisfy human needs for a hygienic and healthy indoor climate and to control the humidity conditions. The required ventilation must be evaluated on the basis of the indoor air quality and the humidity conditions, respectively. It follows that the necessary outdoor air supply must be determined on the basis of the criterion resulting in the largest requirement. Irrespective of whether the dwelling is ventilated naturally or by means of a mechanical ventilation system the ventilation, i.e. the substitution of the indoor air with outdoor air, is associated with consumption of energy for heating the supplied outdoor air. In connection with efforts to reduce energy consumption for ventilation in dwellings it is not to be recommended simply to reduce the basic ventilation. The basic ventilation is the standard performance of the ventilation system.

2.1 Ventilation needs – indoor air quality

The indoor air quality is generally governed by the concentration of bioeffluents and CO_2 originating from humans, contaminants from tobacco smoke and emissions from building products and furnishings.

High concentrations of bioeffluents, of which CO_2 is one component, is the most common reason the indoor air is rated stuffy, smelly and unpleasant. As viewed from the perspective of an odour criterion, the criterion put forth by a person adapted to the room air quality, and solely based on CO_2 originating from humans, it is generally recognised that the supply of outdoor air must be in the order of 3,5-4 l/s per person.

Tobacco smoke consists of both gaseous contaminants and particulate and it is considered the primary source for respiratory dust in the indoor air. The outdoor air supply must be increased considerably in order to maintain acceptable air quality in rooms where smoking is taking place. Considerations on the ventilation requirements in connection with tobacco smoking concern mainly rooms in office buildings and institutional buildings where both adaptation and first-hand impression of the air quality is of importance. In dwellings, however, it have to be considered logical to believe that inferior indoor air quality will be remedied by the occupants by means of opening windows and/or doors. Therefore, a reasonable assumption is that the ventilation system in dwellings is not to be dimensioned on the basis of tobacco smoking.

In recent years increasing attention has been paid to the emission of contaminants from building products and furnishings and the influence these contaminants may have on the indoor air quality. Reduction of the influence from these contaminants should appropriately be done through eliminating the source and the current Danish Building Regulations include special sections specifying provisions and requirements to the use of a number of materials indoors. In addition, during 1994 the Danish Indoor Climate Labelling was established. Both initiatives have resulted in a significant product development and there are reasons to believe that in the future emissions from building products and furnishings will have still less influence on the indoor air quality.

The Danish Building Regulations include provisions aiming at protect against entry of radon and soil gas. Till now investigations on the effect of the provisions do not exist, as the provisions are still very new. It is estimated that only in special circumstances will it be necessary to arrange the ventilation in a dwelling according to potential problems from pollution of the soil.

2.2 Ventilation needs – humidity

The purpose of controlling the humidity conditions in a dwelling is to prevent condensation on surfaces and in the construction itself, to reduce the risk of mould growth and to limit the number of house dust mites.

Condensation on surfaces and inside construction details can lead to damages and early destruction of the materials. Based on the humidity supplied to the room air from typical moisture sources in a dwelling and based on calculations of maximum allowable increase in the water content of the room air regarding condensation an average outdoor air supply of about 7 l/s per person during the heating period is generally considered sufficient. In dwellings of typical size this will correspond to about 0,35 l/s per m^2 and this in turn corresponds to an air change rate of about 0,5 times per hour. As both moisture sources and the production of moisture may be unevenly distributed in time and place there are reasons regarding both energy and indoor climate to investigate the possibilities of controlling the outdoor supply. The outdoor air supply should be controlled so that instead of a continuous supply of 0,35 l/s per m^2 the supply should be periodically higher and periodically lower and at the same time the distribution of the air supply between the individual rooms in the dwelling should be in accordance with the actual moisture production.

Regarding mould growth in buildings a number of large-scale research projects have been initiated in Denmark. The results of the projects will improve the existing knowledge on mould growth and also provide a basis for development of efficient, safe and economically sound solutions for the prevention and remedy of mould growth in both existing and new buildings.

Prevention of mould growth is based on use of well thought out construction details, choice of materials which answers to its purpose and ensuring the necessary outdoor air supply. Regarding the use of ventilation as parameter mould growth must be controlled through the prevention of condensation on surfaces and through keeping the relative humidity of the room air at a sufficiently low level. A reasonable assumption is that if the air supply is maintained at a level that will prevent condensation (see above) and general recommendations for controlling the number of house dust mites are followed (see below) the risk of mould growth will be reduced consequently.

General recommendations for controlling house dust mites are that the moisture content of the room air during a couple of months in the heating season should not exceed 7 g of water per kg air, corresponding to a relative humidity of about 45 percent at normal room temperatures, 20-22 °C.

3. CALCULATIONS

Using CONTAM-96 [36] a number of scenarios regarding the ventilation conditions in a dwelling have been simulated. The simulations are aiming at providing a basis for evaluations of the consequences of controlling the basic ventilation so that it is not permanently 35 l/s but periodically higher and periodically lower.

The simulations have been performed as cyclic calculations in time steps of 5 minutes. Diurnal stationary conditions were typically reached after simulating 3-5 days, and the calculated air flows, contaminant concentrations, relative and absolute humidities etc. of the last day is taken as the result of the simulation.

3.1 The dwelling

The basis for the simulations is a typically sized and traditionally equipped dwelling with two occupants in combination with assumptions on the occupants' use of the dwelling and consequential variations in moisture and pollution loads. Figure 1 is showing a plan of the dwelling. Air is extracted from the kitchen and from the bathroom while outdoor air is supplied through outdoor air inlets in the bedroom and in the living room.

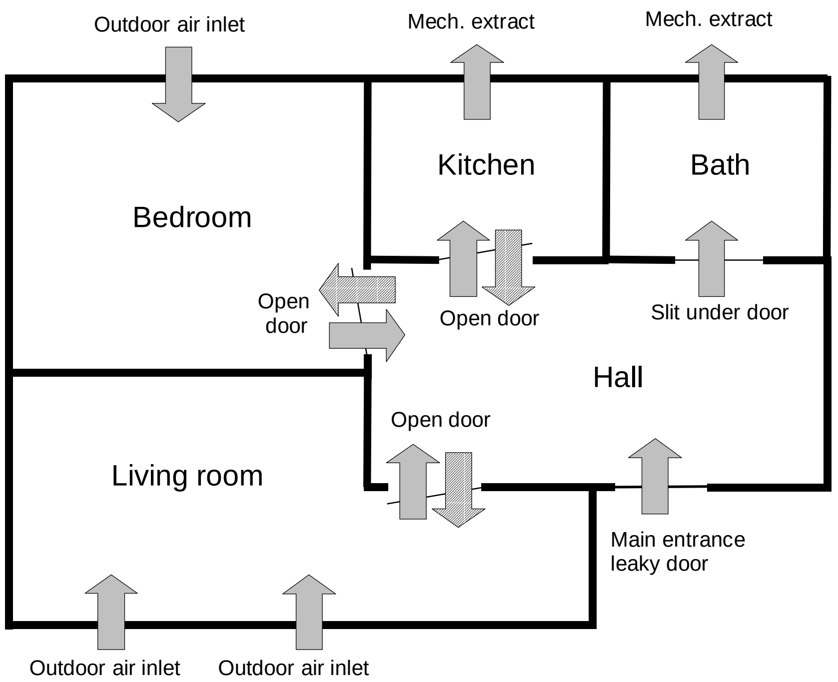

Figure 1. Plan of the simulated dwelling. Assuming equal room temperatures internal air transfer will solely be from bedroom and living room via hall to kitchen and bathroom governed by the mechanical extract in kitchen and bath. The dark-hatched arrows indicate two-way airflow through the internal doors when different room temperatures are assumed.

3.2 Moisture and pollution loads

Table 1 is presenting the assumed use of the dwelling and the diurnal moisture and pollution loads. The overall moisture load is 3,9 kgH_2O per day. In comparison, assuming the dwelling had been in use throughout the day the moisture load would have been 6,3 kgH_2O per day and assuming four occupants the moisture load would have been 11,2 kgH_2O per day.

The calculations include two types of contaminant sources. One is CO_2 originating from the occupants and one is a contaminant source located in the living room. The contaminant source in the living room is aimed at supporting evaluations of emissions from building products and furnishings. In order to maintain clarity the contaminant source is considered dimensionless, located in the living room only and the background concentration is assumed zero. Also, the emission rate is considered constant and adjusted so that in all of the scenarios investigated the concentration in the room air will be between 0 and 100.

Table ***Error! Unknown switch argument.****. Assumed use of the dwelling and diurnal moisture and pollution loads.*

Time	Bedroom	Living room	Hall, kitchen, bathroom
00:00-01:00	15 gH_2O/h	2 persons: 60 $gH_2O/h/person$ 20 l $CO_2/h/person$ 60 $gH_2O/h/person$ 15 gH_2O/h Contaminant emission	**Hall:** 15 gH_2O/h
01:00-07:00	2 persons: 25 $gH_2O/h/person$ 12 l $CO_2/h/person$ 15 gH_2O/h	15 gH_2O/h Contaminant emission	**Hall:** 15 gH_2O/h
07:00-08:00	15 gH_2O/h	15 gH_2O/h Contaminant emission	**Hall:** 15 gH_2O/h **Kitchen:** 2 persons: 20 l $CO_2/h/person$ cooking 200 gH_2O/h **Bathroom:** 2 pers., 2 x 10 min: 20 l $CO_2/h/person$ bathing: 2000 gH_2O/h
08:00-18:00	15 gH_2O/h	15 gH_2O/h Contaminant emission	**Hall:** 15 gH_2O/h
18:00-19:00	15 gH_2O/h	15 gH_2O/h Contaminant emission	**Hall:** 15 gH_2O/h **Kitchen:** 2 persons: 20 l $CO_2/h/person$ cooking: 200 gH_2O/h
19:00-24:00	15 gH_2O/h	2 persons: 60 $gH_2O/h/person$ 20 l $CO_2/h/person$ 60 $gH_2O/h/person$ 15 gH_2O/h Contaminant emission	**Hall:** 15 gH_2O/h

3.3 Scenarios

Five scenarios have been investigated. Scenario 1 is a simple scenario with constant, continuous, mechanical extract from kitchen and bath – 35 l/s in total according to the current Danish Building Regulations – and equal temperatures in the rooms.

Scenario 2 is almost the same as scenario 1, but in scenario 2 different temperatures in the rooms have been assumed. Different temperatures in the rooms mean that two-way airflow through the internal doors will occur, and hence the contaminant emitted in the living room can be found in the air in the bedroom.

In scenario 3 the mechanical extract from kitchen and bathroom is not constant 35 l/s, but increased to 70 l/s in the morning and in the early hours of the evening. During day-time and during night-time 20 l/s is extracted. On average 25 l/s is extracted being about 75 percent of the requirement in the current Danish Building Regulations.

In scenario 4 further fine-tuning of the outdoor air supply is done as the air is supplied to bedroom and living room according to the use of the rooms. On average 25 l/s is extracted.

Scenario 5 is the same as scenario 4 regarding control of the supplied and extracted air. The outdoor climate, however, is assumed to be a typical winter day while in scenario 1-4 the outdoor climate is assumed to be autumn.

4. RESULTS

Space allows only concise reporting of the results from the simulations. More elaborate presentation both in text and figures can be found in [31]. As an example of the presentation of the results figure 2 is showing results concerning the bedroom and the living room from scenario 1, the simplest scenario. In [31] figures are presented for every room in the dwelling and for each scenario.

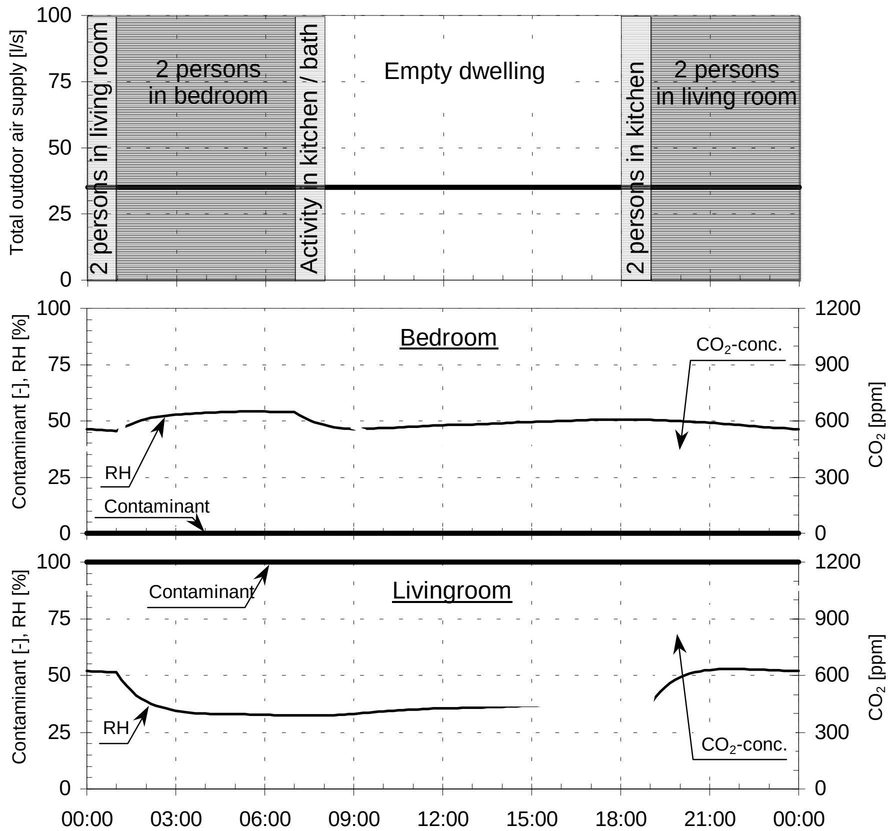

Figure 2. Scenario 1. Topmost is shown the occupants use of the dwelling and the outdoor air supply. Below results of the simulation regarding bedroom and living room is shown.

Figure 3 below is summarising the results from the 5 scenarios concerning the relative humidity, the CO_2-concentration and the contaminant level, respectively in the bedroom and in the living room.

In scenario 1 equal temperatures in the rooms were assumed. As can be seen from the figure this results in a concentration of 100 (dimensionless) of the contaminant emitted in the living room and 0 in the bedroom. In scenarios 2-5 more realistic two-way airflow through the internal doors were assumed leading to non-zero concentrations in the bedroom.

In scenario 1-4 the outdoor climate is assumed to be typical autumn regarding outdoor temperatures, wind direction and wind speed while in scenario 5 the outdoor climate is assumed to be typical winter. It appears from the topmost chart in figure 3 that during wintertime the cold outdoor air results in a lower indoor relative humidity.

In the bedroom the CO_2-concentration peaks close to 1200 ppm when solely outdoor air is ventilating the room (scenario 1).

Even though the outdoor air supply on average is the same in scenario 3 and 4, the more fine-tuned control of the outdoor air supply in scenario 4 results in lower average values and maximum values. Considering that scenario 1 is an accepted (however not recommended) situation in relation to the Danish Building Regulations and scenario 2 is a more commonly found situation the simulations indicate that the basic ventilation may be reduced compared with existing provisions if combined with expedient control strategies.

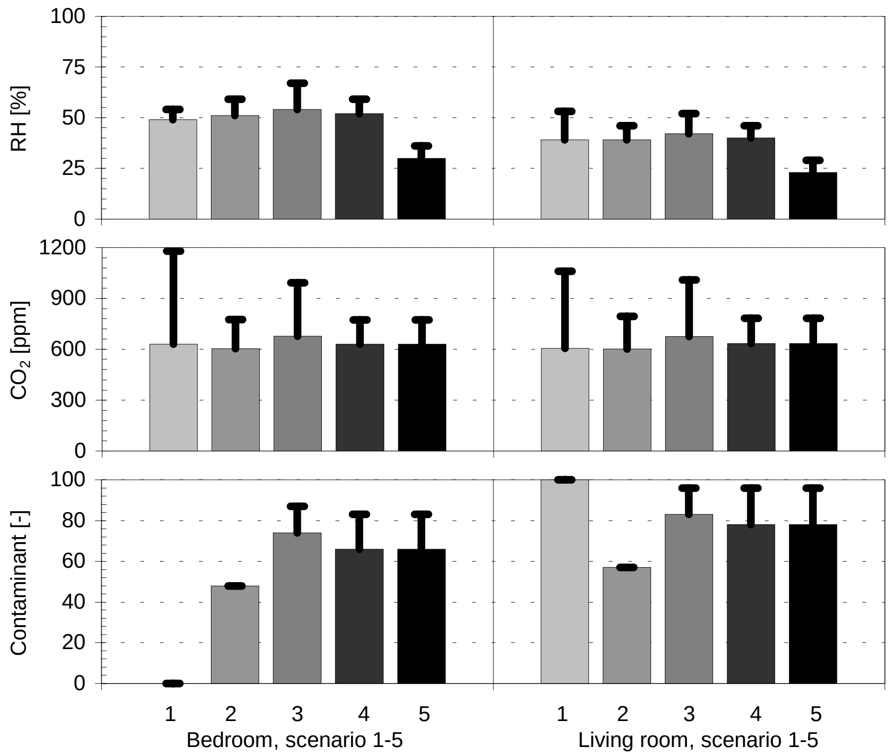

Figure 3. Relative humidity, CO_2-concentration and contaminant level in bedroom and living room in the 5 scenarios. The bars are showing the diurnal average values while the markings above the bars are showing maximum values.

5. CONCLUSIONS

Based on the provisions in the current Danish Building Regulations and on existing knowledge about contaminants in the indoor climate originating from bioeffluents and CO_2 from humans, tobacco smoke and emissions from building products and furnishings, the humidity conditions are regarded as determining for the ventilation requirements in future dwellings.

The simulations have shown that in a typical dwelling and with the assumed use it is possible through appropriate control of the outdoor air supply to reduce the basic ventilation compared with current provisions. The calculations indicate that on average the basic ventilation can be reduced by 20-30 percent without compromising the indoor climate.

If the concentration of contaminants in the room air is taken as the basis for the evaluations the simulations and calculations have shown that regarding *indoor climate* it may be considered acceptable to reduce the basic ventilation. However, this will not for certain satisfy general recommendations concerning *maximum allowable humidity* indoors. Therefore, it is of vital importance that best possible use is made of the outdoor air supplied, i.e. supplying air in time and place according to actual needs. This presupposes the envelope of the dwelling is tight and the outdoor air is supplied through well-defined and suitably placed openings.

There is a need for development of appropriate ventilation strategies that will ensure good indoor climate and reliable control of the ventilation.

6. ACKNOWLEDGEMENTS

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