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Energy Efficient Ventilation of Bathrooms

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Synopsis

This paper reports on the findings from two extensive laboratory studies of ventilation of bathrooms of different sizes and layout of ventilation. The ventilation flow rates were varied. Moisture production were due to laundering and shower baths. In one of the studies the bathroom was provided with a drying cabinet. The extract air was forced to pass through the drying cabinet which was connected to the extract ventilation system of the house by a duct running from the cabinet to the extract air terminal device. Two alternative connections of the drying cabinet to ventilation system of the house were tested; a standard hose directly connected to the extract terminal device (direct extraction) and a hose wich ends just before the terminal device (indirect extraction). To save energy the drying cabinet was not heated but provided with a small mixing fan to enhance the mixing within the cabinet. Two alternative locations of the intake of air to the drying cabinet were tested. The humidity, air-exchange efficiency and local mean age of air were monitored during the test. The drying of the wash was recorded by continuously recording the change of weight of the wash.
Selection of layout of ventilation was based on results of recorded distribution of local mean age and the target for moisture exposure was to minimise the time of exposure of relative humidity higher than 70 %.

Introduction.

The bathroom is the main principle area of moisture and water vapour production. In Sweden people have changed their washing habits and people living in multi family houses want to do the daily washing of their cloths in their bathrooms instead of using the washhouse belong to the house. To dry the laundry they install drying cabinets. Drying of the laundry is the most energy consuming part of the washing "process". Therefore if unheated drying cabinets instead of heated cabinets are installed a substantial amount of energy will be saved (for Sweden the saving is estimated to be between 0.5 -1 Twh) . In an unheated drying cabinet the drying of the laundry is arranged by forcing the ventilation air to pass the drying cabinet. During the passage of the air through the drying cabinet its temperature is lowered. The challenge is to provide an adequate ventilation of both the room and the drying cabinet. If the ventilation does not work properly severe damage to the building may be caused by condensation on surfaces and long time exposure of high relative humidity levels.

Means to control the humidity in the bathroom

To limit the risk for mould growth etc. the aim is to keep the time of exposure to high relative humidity levels as short as possible. There is a risk for mould growth to occur when the relative humidity is higher than 70 % therefore in this investigation the target was put to minimise the time of exposure to relative humidity higher than 70 %. One has the following control methods:

-Source control

-Ventilation
Flow Rate
Distribution of air

-Temperature
Surface temperature
Room air temperature

Drying of the wash in a separate drying cabinet is one example of source control. By dilution of air with less content of humidity than in the bathroom the relative humidity will be reduced. Efficient distribution of the supplied air is a prerequisite for an energy efficient ventilation. By heating of the room air the moisture holding capacity of the air will increase and the relative humidity will be lowered. Local heating of the most exposed parts, e.g. under the bathtub, is one possibility. However, all kind of heating requires energy.

Where may the problems occur ?

The most vulnerable point in the room are the parts of the room surfaces with the lowest temperature and regions with bad ventilation. The internal surface temperatures depend on the quantity of heating, on the indoor and outdoor temperatures and on the thermal resistance of the external walls. Cold bridges does not always occur at joints. Some types of wall constructions have their lowest thermal resistance at the centre of the wall. However, the *lowest temperature* occurs usually at the lowest parts of the wall, see Figure 1. This is due that the loss of heat gives rise to a downdraught of air along the wall surface.
After a shower bath the walls are covered with a film of water which is transported towards the floor. Therefore the floor area is the part most exposed to humidity. Due to the presence of obstacles the air may have difficulties to reach under the bath tube. Room corners may be less ventilated due to that the primary air stream is deflected before it reaches the corners[2].

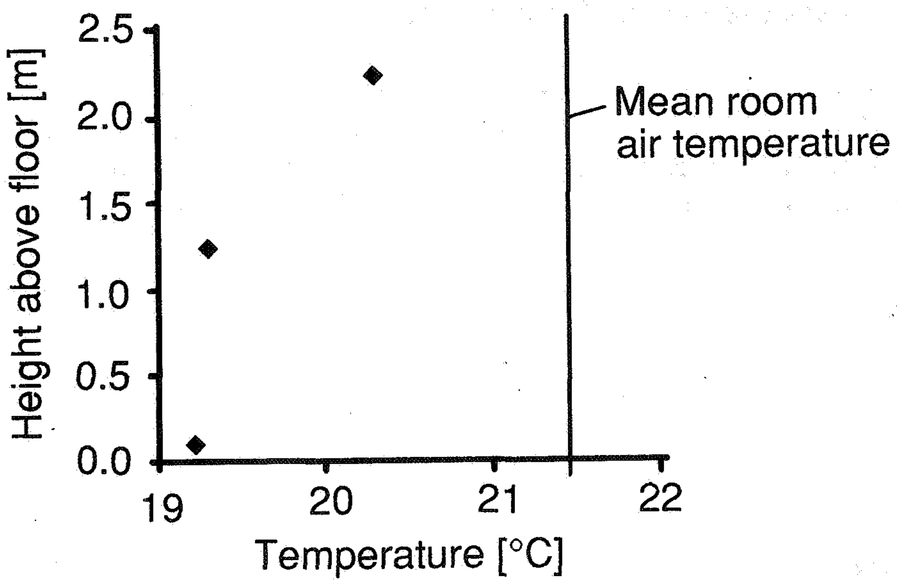


***Figure 1** Example of recorded internal surface temperature of an exterior wall. (from small bath room in Fig. 2)*

Description of test facilities

The tests were accomplished in the indoor testhouse located in the laboratory. One facade of the testhouse is the facade of the laboratory. The testhouse is described in [1]. Two sizes of bath rooms were investigated, see Fig.2.

The pertinent data for the bathrooms is given in the table below.

Bathroom	Volume $[m^3]$	Flow Rate $[m^3/h]$	Flow Rate [litre/s]	Nominal Time Constant [minutes]
Large	13.2	30	8.3	26.4
		55	15.3	14.4
Small	7.8	18	5.0	26.0
		54	15.0	8.7

The door was always closed in all tests to represent a "worst case" situation. The bathroom is ventilated by an extract fan and incoming air comes from the other rooms of the house via purpose made openings between the door and the doorframe. The bathroom shown at bottom of Fig. 2 is provided with a drying cabinet connected indirectly to the extract thermal device of the room (indirect extraction). The main idea behind using such type of connection is to make the drying cabinet independent of the ventilation system of the house in the sense that it will not give rise to any pressure drop.

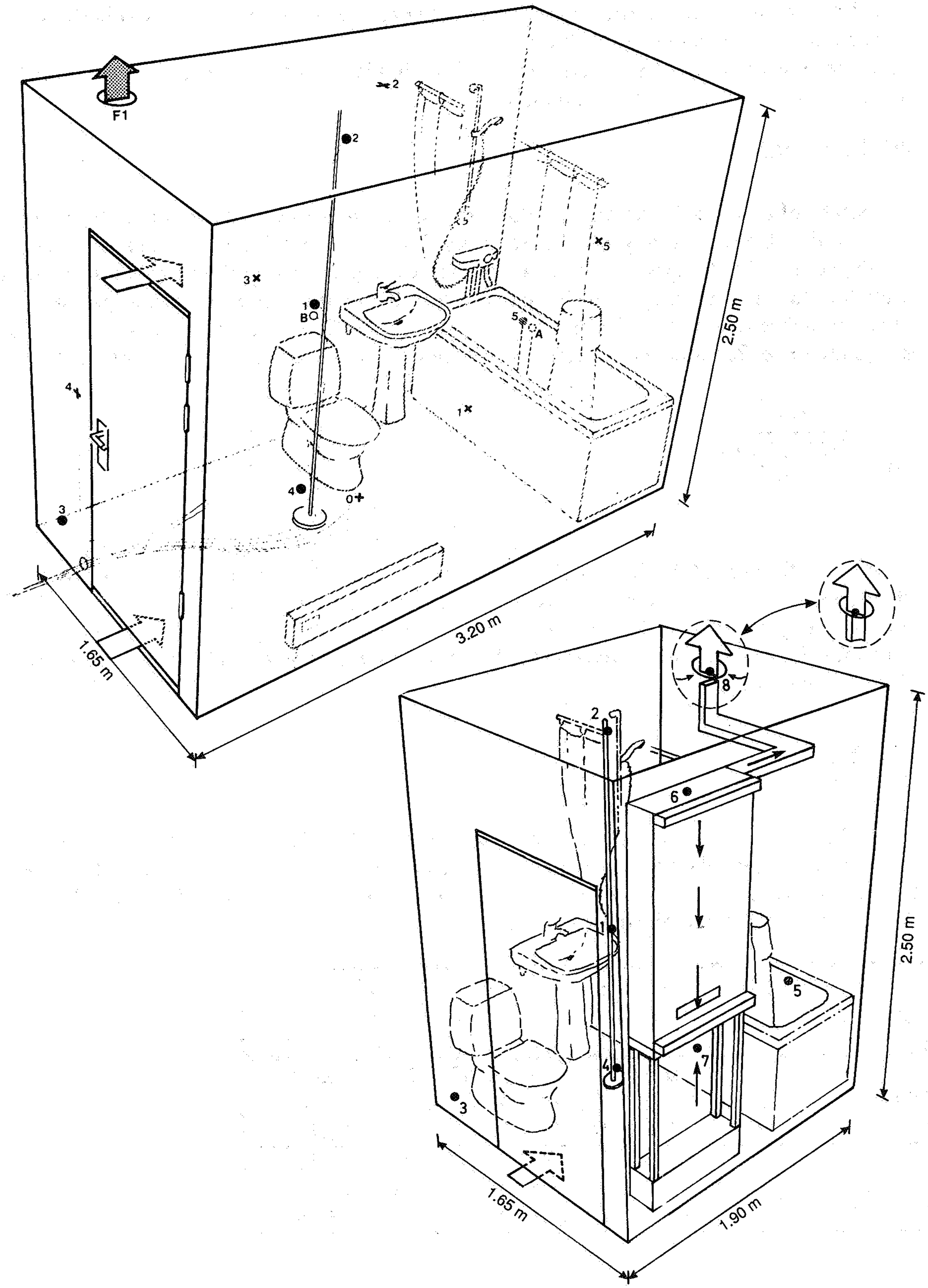


Figure 2 *Large bathroom without drying cabinet*
Below: Bathroom provided with drying cabinet with indirect extraction.
Inset shows direct extraction.

It will thereby not influence the balancing of the ventilation system. As an inset is shown a standard direct connection with a hose..
In the tests with the small bathroom the humidity in the remaining rooms were controlled and the target was set to 50 % relative humidity.

Air Distribution

The intake of air to the bathroom was through a 2 cm gap between the door and the doorway. This implies that one has a type of three-dimensional diffuser with width equal to the door width (71 cm). The temperature in the bathroom was higher than in the neighbouring rooms. Therefore the air streaming through the gap enters the room as a *non-isothermal jet* and is therefore influenced both by inertia and buoyancy forces. The relative strength of inertia and buoyancy forces are grouped together into the non-dimensional *Archimedes number Ar*

$$\mathrm{Ar} = \frac{g\frac{\Delta\theta\sqrt{A}}{(273.33+\theta)}}{U^2} \tag{1}$$

Where A is the area of the "diffuser" , U is the mean velocity and $\Delta\theta$ is the temperature difference between the incoming air and the room air. With increasing distance from the supply a buoyant jet is gradually more influenced by the buoyancy forces. The transition to a buoyancy dominated flow is characterised by a quantity known in fluid mechanics as the *thermal length* l_m.

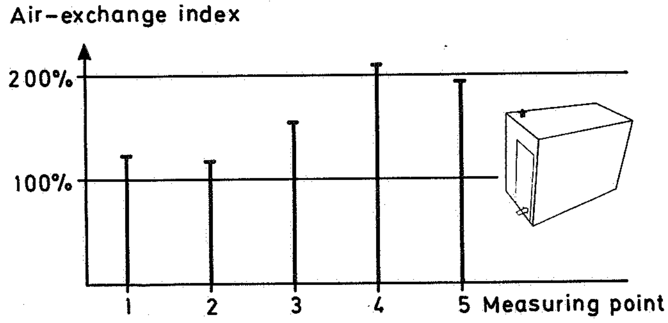
$$l_m = \frac{\sqrt{A}}{\mathrm{Ar}} \tag{2}$$

If this thermal length is much longer than the *perimeter,P,* of the room in the direction of the flow one can expect the buoyancy having minor influence on the flow. The table below gives the pertinent data of the supply device and the supply velocity U, Reynolds number Re, Archimedes number and the thermal length.

q [l/s]	*U* [m/s]	*Re* [1]	$\Delta\theta$ [°C]	*Ar* [1]	l_m [m]	l_m/P [1] Small	Large
5 l/s	0.35	2 800	0.5	0.0175	6.85	0.78	0.60
			1	0.035	3.42	0.39	0.30
			2	0.070	1.71	0.19	0.15
15 l/s	1.06	8 480	0.5	0.0019	63.0	7.16	5.52
			1	0.0038	31.5	3.58	2.76
			2	0.0076	15.7	1.78	1.38

Figure 3 shows for the large bathroom tests with different locations of the intake of air to the bathroom. The *local mean age of air* $\overline{\tau_p}$ was recorded at the points indicated by the filled circles. Standard decay method employing active tracer gas technique was used. Of special interest is measuring point No 5 which is located behind the bathtub. The result is presented in terms of the *local air-exchange index* according to the following definition

$$\varepsilon_i = \frac{\tau_n}{\overline{\tau_p}} \bullet 100 \cdot \ [\%] \qquad (3)$$



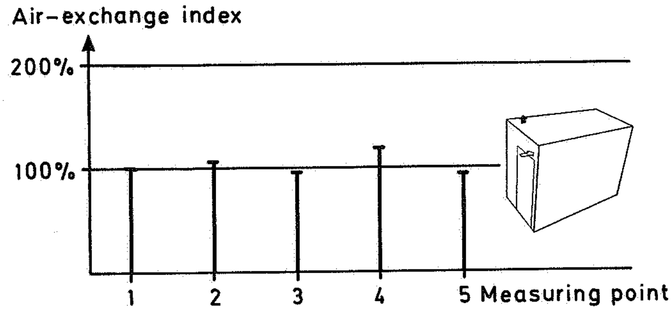


***Figure 3** Large bathroom. Recorded distribution of the local mean-age air for two locations of intake of air. Nominal time-constant 0.24 hours.*

One sees that with the intake located below the door the air arrives behind the bathtub twice as fast as with the intake above the door. Based on these results it was decided to locate the intake of air below the door.

The next figure shows the recorded air-exchange efficiency for the smaller bathroom and with an unbroken connection between the drying cabinet and the extract device of the ventilation system of the room. Therefore the intake of air to the cabinet is the extract point of the air from the room. The intake of room air to the drying cabinet could be located at two alternative positions, at the top of the cabinet or at the bottom of the cabinet. From the upper intake the room air was led to the bottom of the cabinet, see Fig. 2, and therefore the room air entered always the cabinet at its bottom.

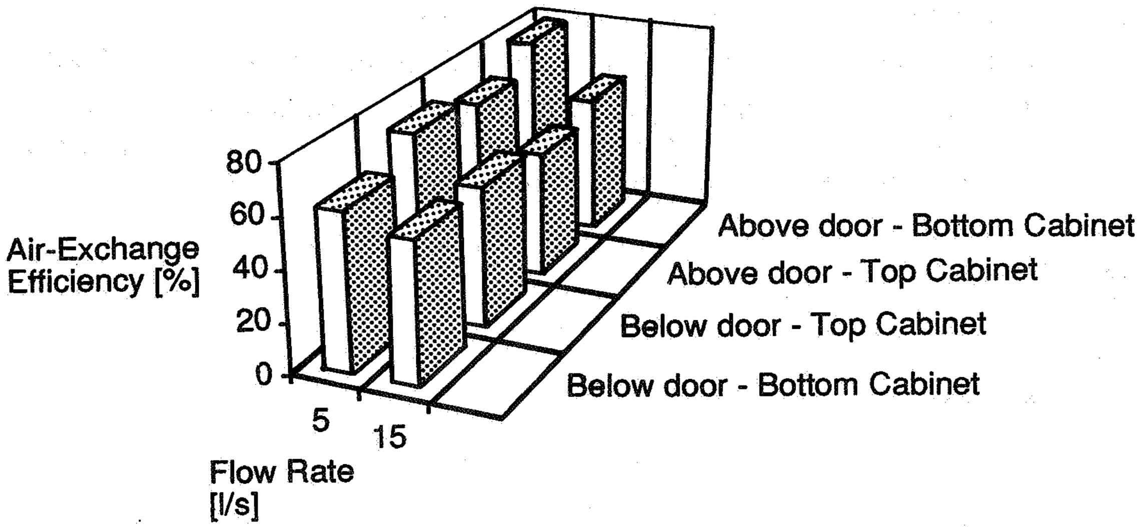


Figure 4. Recorded distribution of local mean age of air.

At the highest flow rate one obtains an even distribution of the air whereas at the lowest flow rate one obtains a more favourable air flow pattern. This can be explained by the analysis in the previous subsection. At the lowest flow rate there is an influence of the buoyancy whereas at the higher flow rate the flow is purely momentum *driven.*

Exposure to humidity

Figure 5 summaries the results obtained for the smaller bathroom provided with a drying cabinet witch was directly connected to the ventilation system of the house.

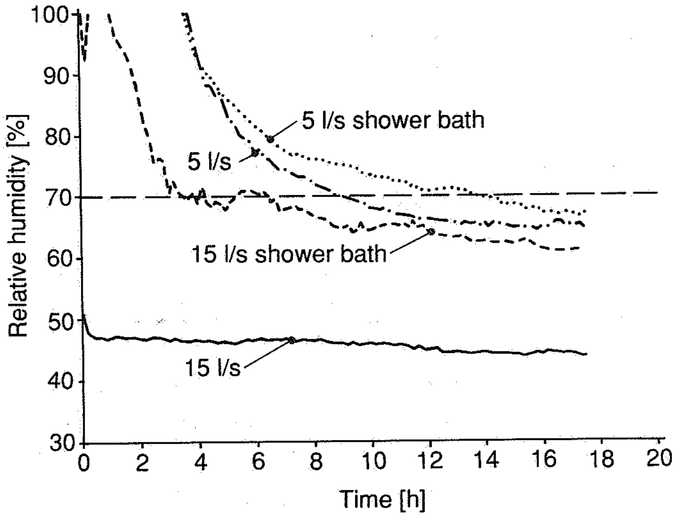


Figure 5 Recorded relative humidity behind the bath-tub at different ventilation flow rates. Duration of shower bath 5 minutes

When the flow rate amounts to 15 l/s the target is met except when taking a 5 shower bath. However the exposure to high relative humidity larger than 70 % is fairly short.

Conclusions

When drying the wash in the bathroom it was possible to meet the target set up for the maximum level of the relative humidity (70 %) behind the bathtub by taking the following steps:

- Install a drying cabinet directly connected to the extract ventilation system
- Flow rate of 15 l/s
- Intake of air to the bathroom at floor level

The drying cabinet was unheated but provided with a small mixing fan (30 watt) in order to enhance the distribution of air within the drying cabinet. The drying cabinet introduced a pressure drop of less than 20 Pascal.
When simultaneously drying the wash in the cabinet and taking a 5 minutes shower bath the air becomes saturated and the target was exceeded during a time period of about two hours.

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