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SPREAD OF GRAVITY CURRENTS WITHIN A MULTI ROOM BUILDING

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ABSTRACT

In dwellings ventilated by extract ventilation there are common complaints of cold draught caused by the supply air entering the room through openings close to the windows. This paper reports on studies of unconventional ways to distribute the supply air in order to minimise the risk of such problems. Experiments have been done where the supply air device is located in the hall of an apartment. The ventilation efficiency in the rooms adjacent to the hall has been studied with open and closed doors.
The behaviour of gravity currents has also been studied in scale models.
Measurements show that it is possible to ventilate rooms using only slots above and below the doors.

KEYWORDS

Extract ventilation, cold draught, gravity currents, air distribution, full scale test, scale model

INTRODUCTION

In dwellings ventilated by extract ventilation there are common complaints during wintertime of cold draught caused by the supply air entering the rooms through openings close to the windows. In order to reduce the problems unconventionally ways can be used to distribute the ventilation air. One way is to use ducts to distribute the supply air to spaces where people usually do not reside for longer periods of time e.g. the hall. However this unconventional location of the supply air devices may result in difficulties to obtain sufficiently good ventilation in some parts of the apartment, especially when the doors between the rooms are closed. When doors are open even very small temperature differences between the rooms cause large airflow rates in both directions through the doorways. Results from measurements of airflow in a doorway between two rooms of different temperature have been reported by Blomqvist, Sandberg (1998). The aim of this work is to investigate if it is possible to ventilate a room using only slots above and below the doors.
This paper also reports on a model scale study of the behaviour 2D gravity currents.

Theory

Figure 1 shows a 2-D gravity current. Entrainment of fluid (ΔQ) from the ambient occurs at the inlet and further downstream the gravity current is heated by the floor.

The velocity is governed by the local buoyancy flux B(x), see e.g. Etheridge&Sandberg (1996)

$$U = kB(x)^{1/3} \qquad (1)$$

Where ,k , is a constant and the buoyancy flux, B, is :

$$B(x) = \frac{Q(x)}{w} g \frac{\Delta\rho(x)}{\rho(x)} = \frac{Q(x)}{w} g'(x) \qquad [m^3/s^3]$$

The height is

$$h(x) = \frac{\frac{Q}{w}}{B(0)^{1/3}} \qquad (2)$$

No heat transfer but entrainment of fluid

In this case the flowrate increases but at the same time the density difference decreases and the buoyancy flux becomes

$$B(x) = \frac{Q(0)}{w} g \frac{\Delta\rho(0)}{\rho(x)} \approx B(0)$$

The buoyancy flux is almost conserved and therefore the velocity and the height are according to relations (1) and (2) constant.

Heat transfer

We assume the floor, which has the temperature T_f, heats the gravity current. The heat transfer coefficient is K [watt/m·K]. For simplicity we ignore the entrainment of ambient air. We obtain the following expression for the reduction in buoyancy flux

$$B(x) = B(0)e^{-\frac{Kx}{\rho C_p \frac{Q}{w}}} \qquad (3)$$

Therefore according to relation (1) the velocity will decrease with increasing distance from the supply.

Mean age of air

The local mean age of air, τ_p, in a room is one indicator of ventilation efficiency and can be determined by tracer gas measurements using the decay method, see Etheridge & Sandberg (1996). If the mixing of the air is complete τ_p is the same in the entire room and equal to the nominal time constant, $\tau_n = V/Q$.

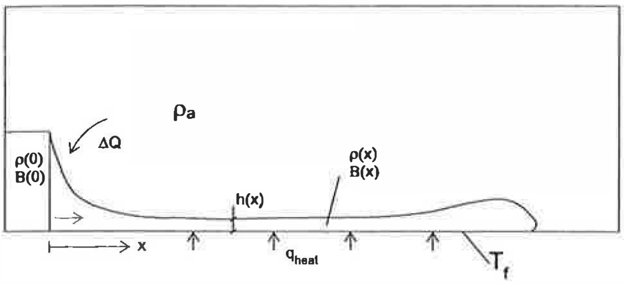

Figure 1 Example of a 2-D gravity current from a low momentum flux device

METHODS

Full scale experiments

For the experiments a test house in the laboratory hall of the department has been used. The house has been designed to look like an ordinary apartment consisting of five rooms (figure 2). The total area of the apartment is $70m^2$ and the corresponding volume, V, is $175m^3$. Air has been supplied as a gravity current in the hall at floor level and the air has been distributed within the apartment through openings above and under the doors. Extract air devices are located in kitchen and bathroom and the total air flow rate, Q, has been 90 m^3/h which is in accordance with the Swedish building code for a dwelling of this size. The nominal time constant for the entire test apartment will then be 1.94 h (V/Q).
The gravity current in the hall has been studied by Thörnström (1998), where the height and the temperature of the current have been determined for various temperature differences.

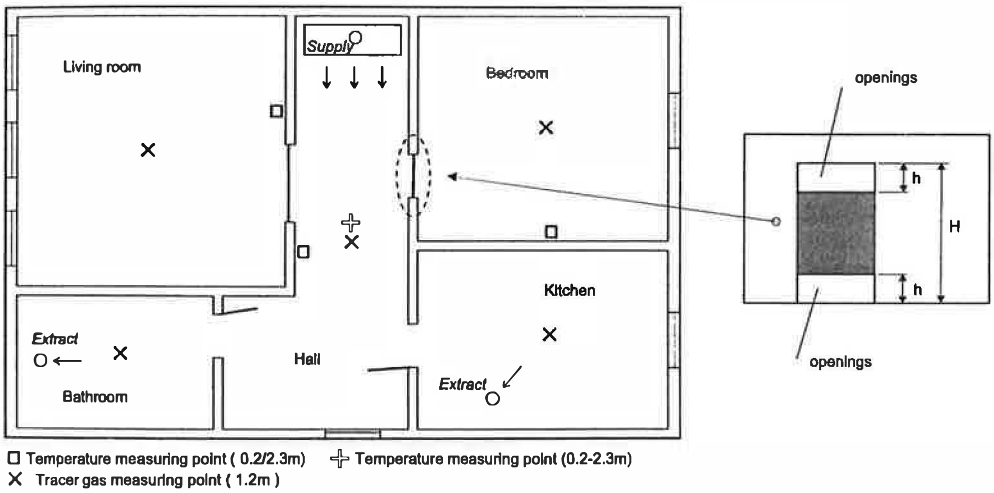

Figure 2. Test house

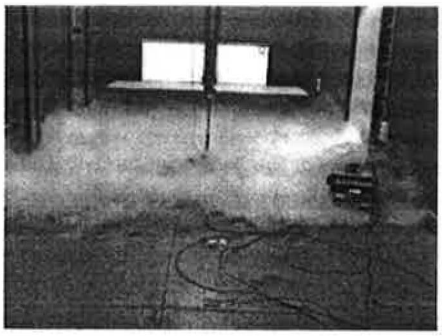

Figure 3. Gravity current from supply air device in the hall advancing towards the viewer

In the middle of each room the local mean age of the air has been determined using tracer gas (decay-method). During these measurements the temperature of the supply air has been approximately 2°C below the temperature in the test building. The height of the slots, h, above and below the doors have been varied from 0.0m (door closed) to 1.00m (door open).
In Figure 3 the supply air in the hall has been visualised by smoke.

Scale model experiments

Figure 4 shows a water model experiment to demonstrate how the supply air can be distributed within the apartment. In the hall the fluid from the supply device is transported as a 2-D gravity current continues as a radial gravity current into the adjacent rooms. Water has been used as fluid and the density difference has been achieved by using saline water as supply fluid. The fluid has been visualised by using coloured dye.

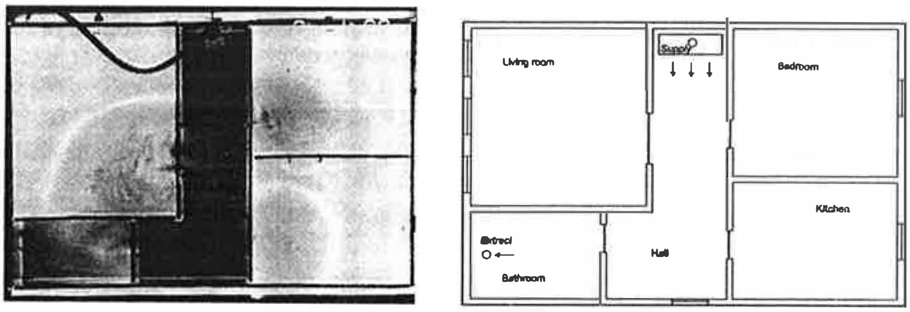

Figure 4. Scale model of the test house with a slot below each door.

To study the behaviour of gravity currents in more detail another scale model has been used. The density difference in the scale model corresponds to a temperature difference in air of 3°C. The length of the model is 2.0m. Test conditions of the experiment can be found in table 1.To make the currents visible the model has been lighted from behind and the gravity current has been videotaped.

TABLE 1
TEST CONDITIONS OF THE WATER SCALE MODEL EXPERIMENT

Height of model	2.00E-01	m	Height of supply	1.02E-01	m
Width of model	7.00E-02	m	Width of supply	7.00E-02	m
Supply flow rate	2.90E-05	m^3/s	Free area	9.74E-04	m^2
Supply density	1.01E+02	kg/m^3	Initial velocity	2.98E-02	m/s
Ambient density	9.99E+03	kg/m^3	Buoyancy flux, B(0)	4.07E-05	m^3/s^3
Reduced gravity, g'	9.82E-02	m/s^2	$B(0)^{1/3}$	3.43E-02	m/s

RESULT

Full scale test

Study of the gravity current in the hall

A picture of the gravity current is shown in figure 3 where the incoming air has been visualised using smoke. The height of the current has been estimated to 0.07-0.10 m. Air temperatures and air velocities have been measured along the gravity current. Initial temperature difference is 3.1°C and the ambient temperature of the hall is 25.8°C. The result is shown in table 2. Based on the inlet specific buoyancy flux the theoretical velocity is 0.12 m/s. Effect of the heat transfer from the floor can be seen clearly.

TABLE 2
AIR VELOCITIES AND TEMPERATURES OF THE GRAVITY CURRENT IN THE HALL

Distance from supply [m]	Air velocity [m/s]	Air temperature [°C]
0.0	0.25	22.7
1.0	0.13	23.8
2.0	0.10	24.2
3.0	0.08	24.5
4.0	0.08	24.6
5.0	0.07	24.6

Measurements of the mean age of air in the rooms adjacent to the hall

The mean age of air in each room has been measured for various heights of the openings above and below the door. Figure 5 shows the local mean age of air in the bedroom at 1.2 m above the floor.

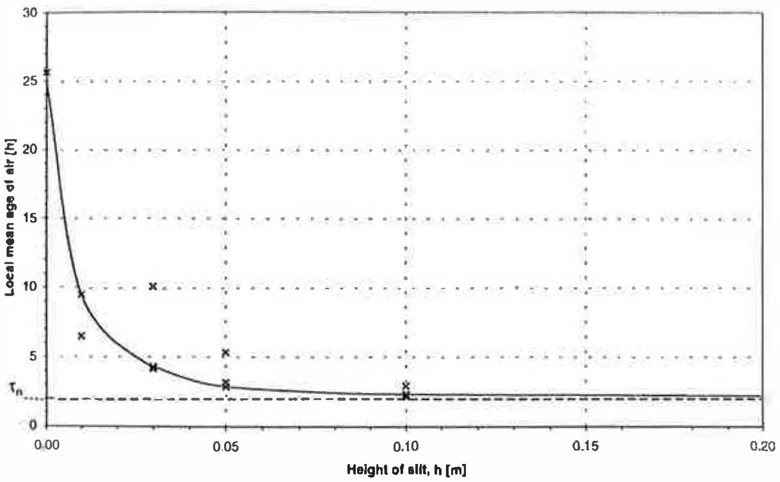

Figure 5. Local mean age of air in bedroom versus height of slot.

When the door is closed (h=0) the mean age of air is high, indicating that the room is not well ventilated. As the height of the opening is increased the mean age of air rapidly decreases. When the height of the opening is 0.10 m the mean age of air is almost the same as the nominal time constant of the apartment which means that the room is almost as well ventilated as when the door is fully open.

Scale model experiments

The 2-dimensional scale model has been videotaped and the velocity of the initial gravity current has been studied. By studying the videotape it has been found that the velocity if the gravity current is constant, (the mean value of k, in relation (1) is equal to 0.84), which is in accordance with theory.

DISCUSSION

The full scale tests show that it is possible to distribute cool air within a building using slots above and below the doors. The velocities close to the floor in the hall are small and will not cause thermal discomfort. One can see that when the openings in the doors become larger the ventilation of the room increases rapidly. When the height of the slots are greater than 0.10 m the mean age of air is almost independent of the size of the opening. This corresponds well to the observed height of the gravity current from the supply air device.
The experiments show that there are good possibilities to ventilate a room only by openings above and below the doors. If low velocity devices are used for the supply air there will be no problems of thermal comfort. However the risk of privacy problems is significant due to noise transmission through the openings. Therefore special openings must be developed.

NOTATIONS

C_p	Specific heat at constant pressure [J/kg·K]
$g'=g\cdot\Delta\rho/\rho$	Reduced gravity [m/s²]
K	Heat transfer coefficient [W/m·K]
Q	Flow rate [m³/s]
q_{heat}	Heat flux [W]
T_f	Floor temperature [K]
V	Total volume of ventilated space [m³]
w	Width of inlet [m]
ρ_a	Density of ambient fluid [kg/m³]
$\Delta\rho$	$\rho-\rho_a$ [kg/m³]

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