# MODELING OF AIR FLOW THROUGH A NARROW CRACK

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Abstract

Radon transport in dwellings is significantly given by pressure differences and properties of transport pathways. In order to predict air velocity and air flow, the model of motion of air through narrow cracks was composed. Theoretical calculations, based on numerical solving of a system of differential equations, were compared with measurements carried on a window crack.

Theory

Calculation of air flow through a narrow crack is derived from theory described in [1]. There are two volumes, e.g. two rooms or room and outdoor, filled with a mixture of dry air and vapor. The width of the crack, which connects the volumes, is less then its length. Due to pressure difference in these volumes, a mixture starts to flow in the direction of decreasing pressure. Air velocity, as well as other properties of air that are changing along a crack, can be calculated by solution of system of conservation equations.

General modeling of dry air and vapor flow [2] represents a complicated task that cannot be easily solved. For this reason, the task was partially simplified to make possible the solving of the most frequently incident cases. In order to simplify the general transport equation, steady state system is considered, i.e. all terms with time derivatives are neglected in transport equations. The crack is considered to be a long non-curved hole of rectangular or cylindrical shape. Dimensions of the crack are expressed by its length and hydraulic diameter. Since the length and hydraulic diameter are the most important parameters that influence transport of air, properties of walls of the crack can be also important in some cases. For example, high difference in air and wall temperature can affect dramatically the flow of air due to high energy transfer between air and walls that is directly proportional to the temperature difference. Air, a mixture of dry air and vapor, enters the cracks from a room with a higher pressure. Information on pressure (partial pressure of dry air and particle pressure of vapor) and temperature of air in the point of enter to the crack are required. Temperature, velocity, and partial pressures of dry air and vapor are changing only along the crack in the direction of flow, i.e. the mixture is averaged over the cross section of the crack. Their magnitudes are considered constant facing to wall (vertical direction to the direction of the flow) and dry air and vapor are assumed to be homogeneously mixed. Other air parameters (air viscosity, specific heat, vapor diffusion coefficient, etc.) can be derived from previous quantities. Pressure difference or air pressure in a second volume is a last parameter required for calculation.

The objective of the calculation is to assign variation of temperature, velocity, and partial pressures of air from enter to exit of the crack. These magnitudes depend on position in the crack. They are determined by solving a system of equations. This system comprises equations for energy and momentum balance, dry air mass balance and vapor mass balance. These four differential equations demand four initial conditions, i.e. air temperature, dry air pressure, and vapor pressure close to enter to the crack and pressure of the mixture at the end of the crack. Mixture pressure at the end of the crack is assumed to be equal to air pressure in a room with lower one. Used model takes into account all processes and interactions that could significantly influence the result. The dry air mass balance equation is simple, because flow of dry air is constant from beginning to the end of the crack. Since the flux is equal to a product of velocity and density, any change of velocity in the crack causes contrary change of density. Similar behavior occurs in the case of vapor flow if vapor condensation is not applied. If air humidity is higher then equilibrium humidity at temperature of wall, vapor starts to condensate on it. On the contrary, water can evaporate from wall surfaces to air. Both these effects may significantly change flow conditions due to high energy, which is released and used up during condensation and evaporation respectively. Momentum balance and energy balance equation are more complex, because they comprise effects caused by air contraction and expansion, energy transfer between air and walls of crack, and so on.

The system of four differential equations can be numerically solved with a Runge-Kutte algorithm. For the purpose of numerical calculation, crack is divided to many parts characterizing air and wall properties over cross section of the crack in its certain section. The equations, transformed to the form required for numerical solving, enable to assign temperature, velocity, dry air and vapor pressure in a specific part of the crack from their values in a previous part.

Fig. 1 - In situ measurement of air velocity and pressure difference

## Measurements

In order to verify above mentioned model for air flow through a narrow crack, experiment with a window crack was performed. Fig.1 shows in situ measurement of air velocity and pressure difference. Testo pressure probe was used for recording of pressure differences. The pressure probe works with a differential pressure according to the principle of strain gauge. It measures in a range of 100 Pa with an accuracy of 0.3 Pa. Air velocity was measured with Testo hot bulb probe, which works according to the principle of a thermal sensor. It enables to assign velocities up to 10 m/s.

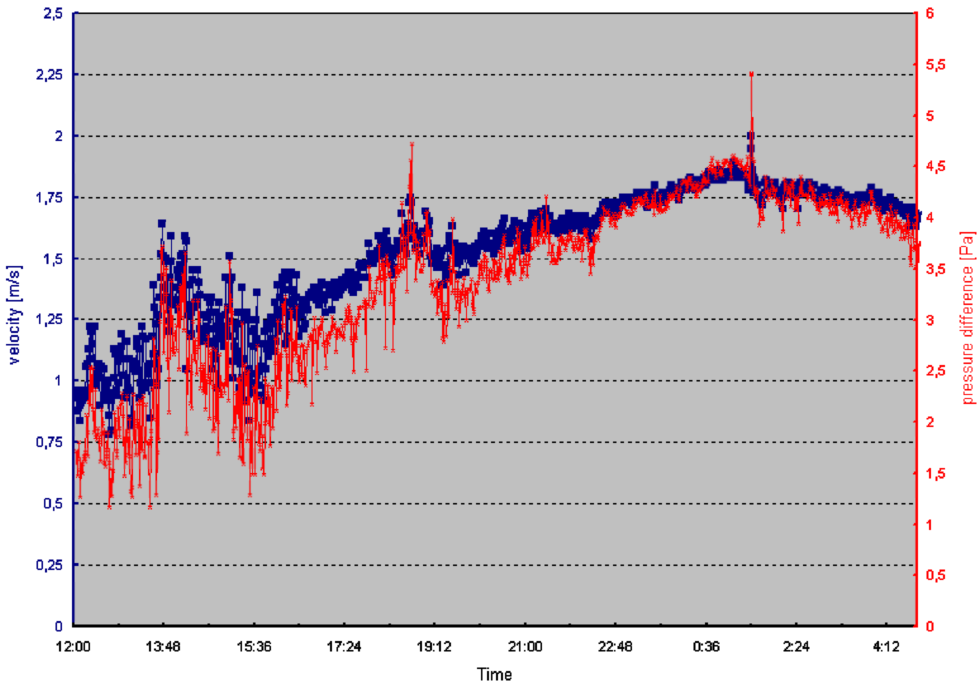


Fig. 2 - Time record of pressure differences and air velocities in window crack

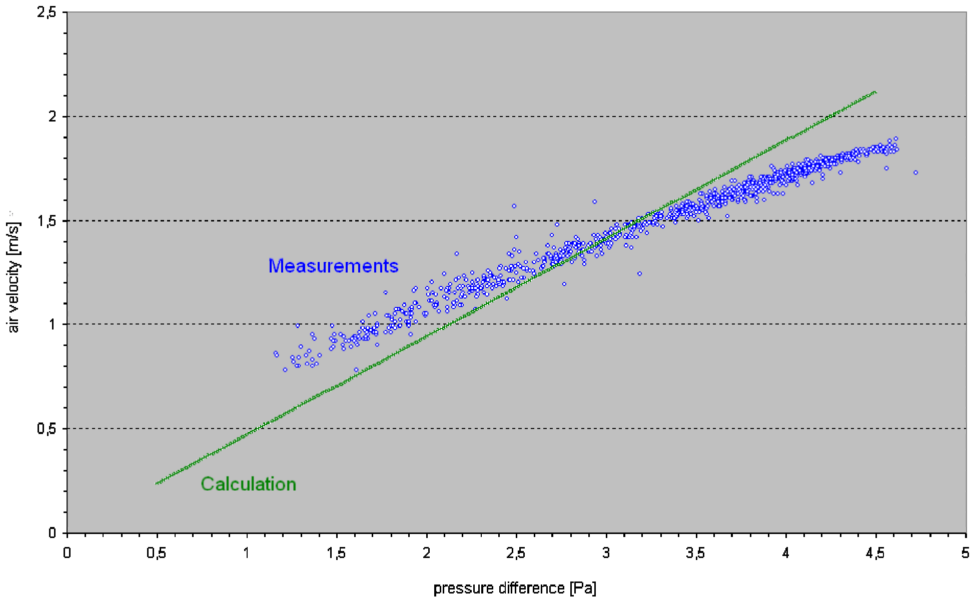


Fig. 3 - Air velocity versus pressure difference – comparison of calculation and measurement

Fig. 2 describes results of nearly one thousand measurements of air velocity and pressure difference at window crack. Experimental data were acquired in one minute intervals from 12 a.m. to 4:30 a.m. The length of the window crack, positioned 80 cm above floor, was 5 mm.

These experimental data were used for verification of theoretical calculation. Fig. 3 compares measurements with a result of theoretical calculation that was done for conditions comparable to measurement ones. Temperature of air and walls of window crack alternated from 22˚C to 24˚C and pressure difference fluctuated approximately from 1.2 Pa to 4.7 Pa. Crack width was estimated to 0.7 mm. Close relation between air velocity and pressure difference is evident.

## Conclusions

The described model enables to calculate air velocity and air flow in different cracks and leakages connecting rooms in dwellings or outside and interior. If radon concentration is known, its transport can be predicted. Fig. 4 represents an example of theoretical calculation. Air velocity and air flow were calculated for a rectangular crack of a length of 3 cm. Dimensions of rectangular crack profile are 1 m and 1, 1.5, or 2 mm. These parameters of the crack nearby correspond to door leakages. Air velocity, as well as air flow, depends considerably on pressure difference and hydraulic diameter of the crack that is in this case derived especially from the width of the crack (1, 1.5, and 2 mm).

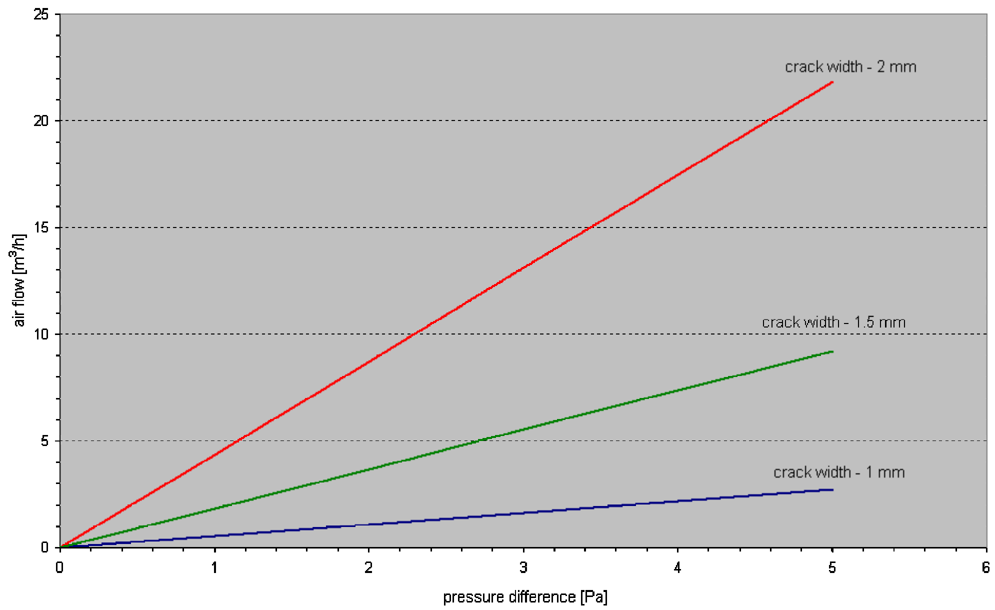


Fig. 4 – air flow versus pressure difference calculated for three rectangular cracks.

## References


[1] Williams, M.M.R.: *A Model for the Transport of Vapour, Gas and Aerosol droplets through Tubes and Cracks*, Progress in Nuclear Energy, Vol. 30, No. 4, pp. 333-416, 1996, Elsevier Science

[2] Nigmatulin, R.I.: *Dynamics of multiphase media*, Vol I, Hemisphere Pub Co., 1991