RELIABILITY OF THE NEW METHOD FOR ASSESSING THE RADON RISK – GAS PERMEABILITY CLASSIFICATION

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Introduction

The new uniform method for assessing the risk of radon penetrating from the underlying soil or bedrock, based on determining the radon index of the building site (1), has become obligatory in 2004 for all radon specialists in private companies and other entities that deal with assessing the radon risk of building sites in the Czech Republic. The method, that is used for the purposes of radon risk mapping (1, 2), too, enables to classify one of the decisive parameters for classification of radon risk in two ways. The permeability of soils and rocks for gases, that is evaluated with respect to the whole vertical profile up to the level of assumed building foundation or to the level of assumed contact building – soil, can be determined by direct *in situ* permeability measurements or by an expert evaluation of permeability. As both ways lead to the final determination of radon risk, we should certainly focus on comparison of the results obtained from both processes.

Direct measurements of permeability

Direct permeability measurements are performed at a depth of 0.8 m beneath the ground surface. The method (3) consists of measuring the airflow during suction from the soil or when pumped into the soil under constant pressure. The procedures used in CR for permeability measurements are similar to those of soil gas sampling (small-diameter hollow steel probes with a free, sharpened lower end - a lost tip). The internal surface area of the cavity formed by pounding out the free tip must be exactly defined for each measurement system. Various devices designed for *in situ* gas permeability measurements can be used. As for the lack of the gas permeability standardization and various other complications (the shape factor of the probe depends on its geometry and internal dimensions, individual corrections for the free flow of air in specific instruments are needed), the results obtained from various devices should be standardized against the RADON-JOK permeameter, widely used in the Czech Republic.

RADON-JOK is a portable equipment, which has been developed for *in situ* measurements of gas permeability of soils. Its robustness and its simplicity is very practical for easy, quick and at the same time sufficiently exact *in situ* investigation. The principle of the RADON-JOK equipment is based on air withdrawal by means of negative pressure. The air is pumped from the soil under constant pressure through a specially designed probe with a constant surface of contact between the probe head and the soil. The constant active area is created in the head of the probe (driven into the soil to a measured depth) by the extrusion of the tip by means of the punch wire inside the probe by an exact distance. The special rubber sack, with one or two weights, pumps the air from the soil and allows to perform measurements at very low pressures. The permeability is calculated using the known air flow through the probe, which is defined by the known air volume (= 2000 ccm) in the rubber sack (depression of the bottom of the sack between two notches) and by the pumping time measured. The great advantage of RADON-JOK is the possibility to perform measurements independently of any source of energy (electricity, compressed air).

For direct *in situ* permeability measurements, the requirements for the number of measurements are the same as for the soil gas radon concentration measurements, i.e. at least 15 measurements for a single building, or the taking of measurements in a 10 x 10 m grid for building sites >800 m^2. The same statistical parameter, i.e. the third quartile of the data set, is used as a decisive value for the assessment, because it diminishes the influence of outliers and local permeability anomalies. However the authorized person responsible for the final classification must consider any local permeability anomalies and variations and the spread of data. The permeability classification for larger areas, where permeability measurements must be made in a 10 x 10 m grid, depends on the homogeneity of the site and the data set (geologically homogeneous site, division into several homogeneous subsites, a zone with distinct permeability, local permeability anomalies).

The permeability is designated by the symbol **k**. When direct *in situ* measurements are performed, the gas permeability is given in $\mathbf{m^2}$ (rounded to one decimal position, e.g. $1{,}7\ .10^{-12}$ m^2).

Expert evaluation of soil permeability

An expert evaluation of soil permeability is necessary when *in situ* permeability measurements are not performed at all sampling points of soil gas radon concentration measurements. This expert evaluation of permeability leads to assigning the low – medium – high categories of permeability and is based on the description of the vertical soil profile. The evaluation must involve following methods:

- The macroscopic description of the fractions in samples from a depth of 0.8 m, with the classification of its permeability (low – medium – high). Estimating the proportion of the fine fraction (particle size <0.063 mm) is the base in this classification, the final corrections are performed with respect to the factors that could influence the actual permeability.
- Evaluating the resistance encountered when drawing the soil gas samples for the radon concentration measurements at all sampling points, and estimating the prevailing permeability category (low – medium – high).

For the better evaluation of vertical and horizontal changes in permeability, the number of performed hand drill tests is imposed with respect to the extent of the measured area. The expert responsible for the evaluation should consider during the process of assessment the influence of various factors on actual permeability (soil moisture, degree of water saturation, effective porosity, porosity, density or compactness, loose texture, occurrence of macro- and micro-fissures, degree of inhomogeneity of the fine fraction, content of the coarse fraction - fragments, cobbles, stony debris, character of the weathering surfaces of rocks, presence of faults, anthropogenic effects on the ground surface or in the upper soil layers - such as deep ploughing or the presence of paths, deep compactness of upper soil layers, presence of concrete or asphalt coverings, vertical and horizontal variability of soil layers with different permeability). Especially in case of larger areas the results of detailed geological or hydrogeological survey at the same areas are very often used for the expert evaluation of soil permeability.

The resulting permeability is classified as low, medium, or high, i.e. only a single evaluation at homogenous sites and the highest category of the separate subsites for a building covering several soil permeability subsites.

Radon index assessment

The final radon index determination is derived from the permeability data.

If the results of both soil gas radon concentration and permeability measurements are available for all measuring points, a radon potential (RP) model can be used for determining the RI. The model enables more precise assessment of borderline cases.

The graphical presentation is given in Fig. 1, the radon potential RP is derived from the building site assessment and defined by the equation [1]. It enables the determination of RI as low, medium, or high (if RP < 10, then RI is low; if 10 ≤ RP < 35, then RI is medium; if 35 ≤ RP, then RI is high).

$$RP = (c_A - 1) / (- \log k - 10) \qquad [1]$$

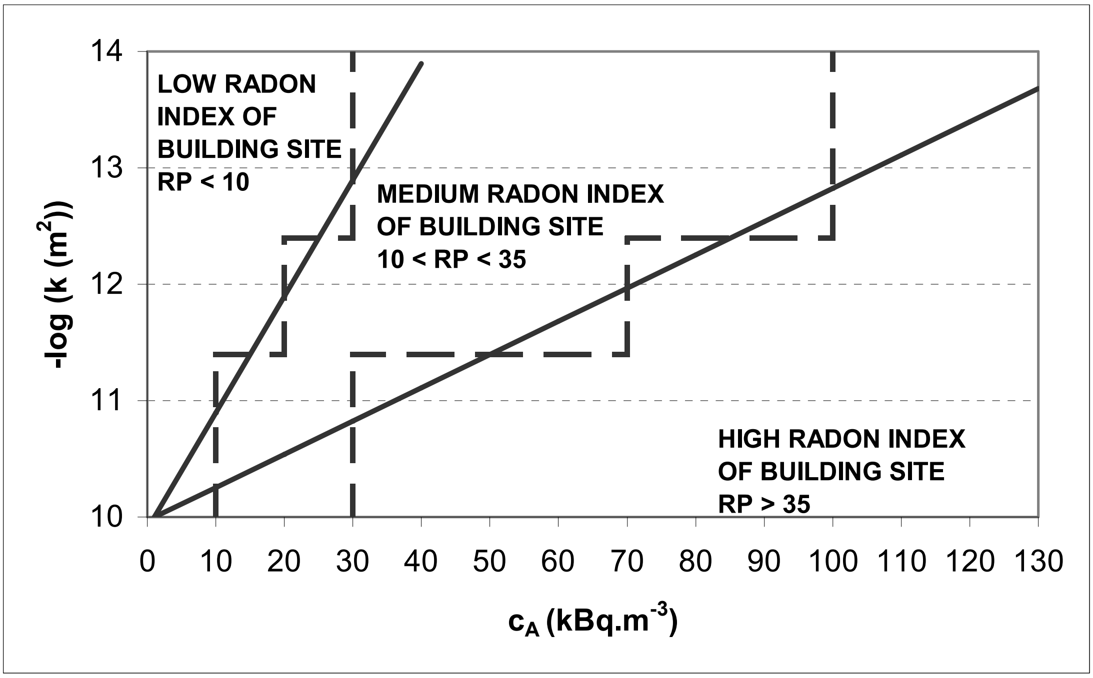

Fig. 1 - Radon potential of the building site

If the expert evaluation of soil permeability is used (i.e. if the permeability is determined without numerical values), the radon index of the building site is assessed using the following classification table (Tab.1); see also Fig. 1 (borders are given by fractional lines separating the categories).

Tab. 1: Radon index assessment

Radon index (RI) category	Soil gas radon concentration ($kBq.m^{-3}$)		
Low	$c_A < 30$	$c_A < 20$	$c_A < 10$
Medium	$30 \leq c_A < 100$	$20 \leq c_A < 70$	$10 \leq c_A < 30$
High	$c_A \geq 100$	$c_A \geq 70$	$c_A \geq 30$
	low	*medium*	*high*
	permeability		

The resulting radon index of the building site (RI) is given as one of the three categories: low, medium, or high.

Comparison of results

In 2004-2005, RADON v.o.s. corp. realized a research project "Investigation of radon transport from the foundation soils to the indoor environment through the contact between the building and the subfloor layers". Although the assessment of radon index was not the main aim of the project, it lay within the necessary conditions for further investigation.

Chosen fifteen houses were situated in various geological conditions, with respect to the fact that the project was focused on higher indoor radon values corresponding to higher radon potential of the ground. Therefore the occurrence of various soil and bedrock types in the set (see Tab. 2) cannot be representative.

Tab. 2: Occurrence of various bedrock types in the set of chosen buildings

Site (house)	**Bedrock**
Růžená No.1	Granite
Louňovice No. 214	Granodiorite
Jindřichov No. 126	Granite
Loučná nad Desnou No. 16	Amphibolite
Kuníček No. 11	Syenodiorite
Potůčky No. 37	Chlorite-sericite phyllite
Horní Slavkov No. 374	Migmatite, Paragneiss
Střížov No. 44	Quartz monzonite
Jablonná No. 82	Granodiorite
Louňovice No. 296	Granodiorite
Horní Slavkov No. 570	Migmatite, Paragneiss
Horní Slavkov No. 519	Migmatite, Paragneiss
Beztahov No. 47	Biotite gneiss
Divišovice No. 17	Granodiorite
Milevsko No. 1408	Granite

The radon index has been determined with respect to the new method (1) as radon potential (RP model, direct measurements of permeability) as well as using the expert assessment of permeability and the classification table. The results of radon index evaluation are summarized in Tab. 3, the graphical presentation of radon potential values is given in Fig.2.

The low radon index as well as the medium one has been observed only once (Loučná nad Desnou No. 16, Střížov No. 44 respectively). In thirteen cases the radon index has been classified as high. How can be seen from the summary, the results of radon index based on direct measurements of permeability and the radon potential model agree with the results based on expert assessment of permeability and the classification table in all cases. That conclusion is valid even in border cases, when the observed values are closed to the border between categories of radon index – house Střížov No. 44, the classification closed to the upper limit of medium radon index, family house Jablonná No. 82, the classification near the lower limit of high radon index.

Some differences were found in case of the evaluation of soil permeability. If we use the border values for RADON JOK equipment, $k = 4,0 \,.\, 10^{-12}\ m^2$ between high and medium permeability and $k = 4,0 \,.\, 10^{-13}\ m^2$ between medium and low permeability, in three cases the category of permeability from expert evaluation does not correspond to the category derived from direct measurements. The lower permeabilities, i.e lower values from direct measurements, correspond to high soil moisture in upper soil layers (Růžená No.1, Horní Slavkov No. 519). The higher permeability from direct measurements in the case of Loučná nad Desnou No. 16 is caused by the statistical evaluation (the decisive parameter is the third quartile).

Tab. 3. The results of radon index: classification based on radon potential model (RP; direct measurements of permeability) and on expert assessment of permeability and classification table; c_{A75} – third quartile from the set of soil gas radon concentration values; k_{75} – third quartile from the set of direct gas permeability measurements

Site (house)	c_A	Permeability		RP	Radon Index	
	Third quartile c_{A75} (kBq.m^{-3})	Expert assessment	Direct m. k_{75} (m^2)		RP	Table
Růžená No. 1	88,4	High	$2,4.10^{-12}$	54,0	High	High
Louňovice No. 214	143,6	High	$1,4.10^{-11}$	167,0	High	High
Jindřichov No. 126	203,7	High	$1,6.10^{-11}$	254,7	High	High
Loučná nad Desnou No. 16	16,7	Low	$1,5.10^{-12}$	9,2	Low	Low
Kuníček No. 11	90,3	High	$1,1.10^{-11}$	94,2	High	High
Potůčky No. 37	70,7	High	$1,6.10^{-11}$	87,6	High	High
Horní Slavkov No. 374	297,7	High	$7,9.10^{-12}$	269,1	High	High
Střížov No. 44	54,6	Medium	$1,9.10^{-12}$	31,1	Medium	Medium
Jablonná No. 82	31,8	High	$1,6.10^{-11}$	38,7	High	High
Louňovice No. 296	122,3	High	$1,1.10^{-11}$	126,5	High	High
Horní Slavkov No. 570	114,1	High	$5,7.10^{-12}$	90,9	High	High
Horní Slavkov No. 519	73,1	High	$3,1.10^{-12}$	47,8	High	High
Beztahov No. 47	234,4	Low	$2,0.10^{-13}$	86,5	High	High
Divišovice No. 17	219,2	Medium	$1,9.10^{-12}$	126,8	High	High
Milevsko No. 1408	319,4	High	$5,2.10^{-12}$	248,0	High	High

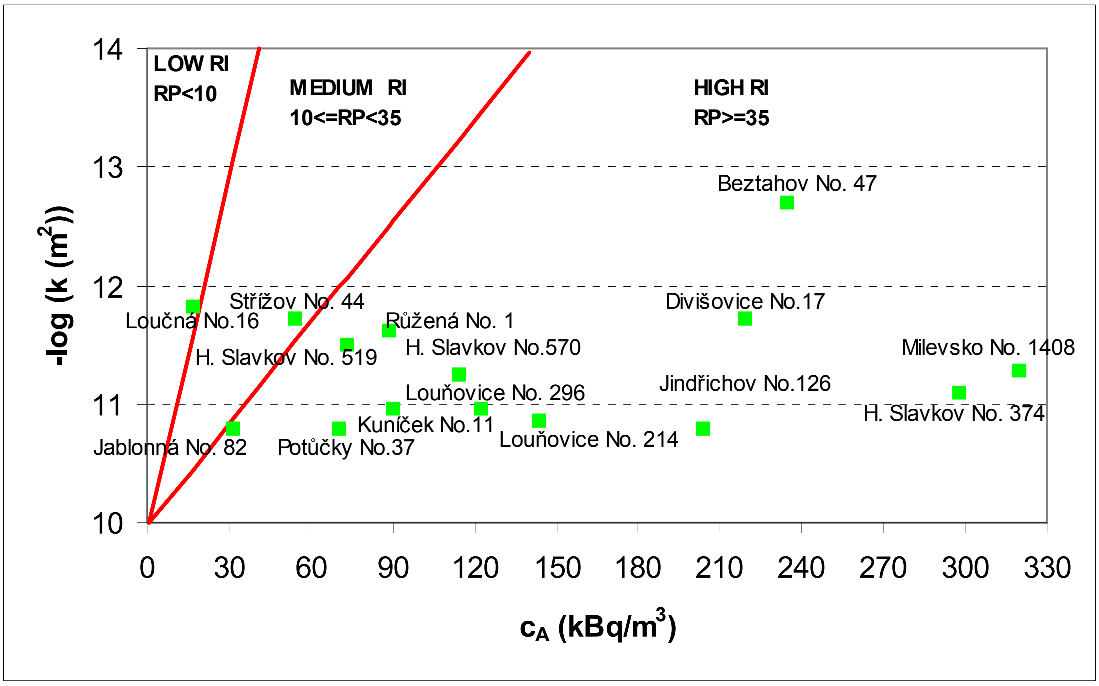

Fig. 2. Results of radon index based on radon potential model and direct measurements of permeability

Tab. 4. Comparison of permeability classification

Site (family house)	Permeability		
	Expert assessment	Direct measurements	
		k_{75} (m^2)	category
Růžená No. 1	High	$2{,}4.10^{-12}$	Medium
Louňovice No. 214	High	$1{,}4.10^{-11}$	High
Jindřichov No. 126	High	$1{,}6.10^{-11}$	High
Loučná nad Desnou No. 16	Low	$1{,}5.10^{-12}$	Medium
Kuníček No. 11	High	$1{,}1.10^{-11}$	High
Potůčky No. 37	High	$1{,}6.10^{-11}$	High
Horní Slavkov No. 374	High	$7{,}9.10^{-12}$	High
Střížov No. 44	Medium	$1{,}9.10^{-12}$	Medium
Jablonná No. 82	High	$1{,}6.10^{-11}$	High
Louňovice No. 296	High	$1{,}1.10^{-11}$	High
Horní Slavkov No. 570	High	$5{,}7.10^{-12}$	High
Horní Slavkov No. 519	High	$3{,}1.10^{-12}$	Medium
Beztahov No. 47	Low	$2{,}0.10^{-13}$	Low
Divišovice No. 17	Medium	$1{,}9.10^{-12}$	Medium
Milevsko No. 1408	High	$5{,}2.10^{-12}$	High

Conclusions

In all 15 cases, the resulting radon index was the same using both methods for permeability determination. Those obtained results are very promising, with respect to the fact that final categorization of radon index is the only and main aim of radon risk assessment using the new uniform method. Values of radon potential are very valuable, because they enable to compare areas with the same radon index. That comparison can be used in analyses of relationship between building and building ground, in selection and design of preventive measures (to avoid any underestimating and/or overestimating approaches), in transfer factor studies as well as in other cases.

As for the permeability classification itself, some insignificant differences in results obtained from both available methods were observed. But those differences do not cause differences in the radon index classification.

Acknowledegement

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