COMPLEX SYSTEM OF RADON DIAGNOSIS METHODS AND SPECIFIC EXPERIMENTAL AND THEORETICAL PROCEDURES APPLIED IN THE INDOOR BUILDING ENVIRONMENT

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ABSTRACT

The paper is aimed at different measuring techniques and methods practically used for a classification of buildings in the context of radiation protection requirements. Specific experimental and theoretical diagnostic procedures designed for identification and quantification of indoor radon entry characteristics are proposed and discussed in detail (continuous simultaneous radon concentration monitoring, blower door technique, infrared Thermography imaging system, continuous soil gas radon measurement, air-exchange rate assessment – tracer gas measurement, visual inspections of buildings, build-up curve numerical analysis, air infiltration parameters assessment etc.). The given system of radon diagnosis was applied and verified on a set of dwellings, covering practically all types of family houses with regards to different types and quality of radon protection measures.

INTRODUCTION

Instantaneous values of indoor radon concentration fluctuate in time and simultaneously feature the significant space variations within the individual compartments of buildings. Generally, the indoor radon concentration is a result of two competing driving processes, the radon entry rate ($Bq.s^{-1}$) respectively air-exchange rate (s^{-1}).

For the purpose of the individual dose estimation due to radon and its decay products exposure, the annual mean indoor radon concentration assessments derived from the solid-state nuclear track detectors measurements are generally provided. The weather conditions and residential habits, including a habitual behavior of occupants, staying time, number of inhabitants, ventilation and heating regime, ventilation and an air-conditioning systems operation etc., are considered as the most significant influencing factors for the indoor radon measurements and radon exposure assessment.

In respect of buildings classification related to preventive and remedial measures efficiency against the radon entry from the subsoil, short-term radon concentration measurements under conservative exposure conditions are usually applied. The measurement conditions are set-up to minimize the false positive results and to avoid misinterpretation accordingly. In this context, a defined range of temperature and pressure field gradient during the measurement is required.
The summary overview of radon diagnosis results focused on the ineffective preventive measures against radon penetration has been presented (Neznal, 2006).

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RADON DIAGNOSIS PROCEDURES

Different measurement techniques and procedures designed for localization and quantification of indoor radon entry characteristics have been tested and applied in respect of primary causes of ineffective preventive and remedial measures identification. Presented modern and sophisticated radon technologies (continuous simultaneous radon concentration monitoring, blower door technique, infrared Thermography imaging system, continuous soil gas radon measurement, air-exchange rate assessment – tracer gas measurement, visual inspections of buildings, build up curve numerical analysis, air infiltration parameters assessment, air pressure differences measurement) have been selected as fundamental elements of a complex radon diagnosis system.

The artificially produced pressure difference levels enable to identify and localize the most important convective component of the radon entry into the building environment.

In order to monitor a distinctive dynamic behavior of indoor radon concentration for specific blower door measurements, a unique continuous radon monitor characterized by a very fast detection response has been designed and applied. Generalized outputs based on qualitative and quantitative analysis of the continuous radon concentration measurements, recorded during the blower door tests, will be performed in detail further in this section.

SIMULTANEOUS INDOOR RADON MEASUREMENT

A simultaneous continuous indoor radon monitoring within the building, including uninhabited areas, can be considered as a primary method of radon diagnosis. The radon transport from the subsoil and indoor radon distribution including appropriate radon infiltration characteristics of individual rooms can be assessed from results of continuous indoor and soil-gas radon measurements. The single room intrinsic properties, the radon entry rate and the air-exchange rate, can be estimated from the appropriate radon concentration build-up curve numerical analysis. In this context, the constant radon entry rate and ventilation rate approximation has been applied (NRPI, 2005). Several difficulties and limitations can occur during the data processing. The major problem of given approach in real conditions is related to the model assumptions concerning the time dependence of entry parameters represented by constant coefficients in the appropriate differential equation (1). In addition, both quantitative parameters depend on pressure field propagation within the building. The pressure difference variations are closely related to the weather condition, the indoor microclimate, height of the building and residential habits. Due to the fact that the infiltration of the radon is driven by the indoor - outdoor pressure difference (a stack effect) the idea of the artificially produced pressure difference is obvious.

$$\frac{\mathrm{d}c_{\mathrm{Rn}}(t)}{\mathrm{d}t} = \Phi_{\mathrm{Rn}} - (\text{ë} + k) \cdot c_{\mathrm{Rn}}(t)$$

$$c_{\mathrm{Rn}}(t) = \frac{\Phi_{\mathrm{Rn}}}{(\lambda + k) \cdot V} \cdot (1 - \mathrm{e}^{-(\lambda + k)t})$$

Equation (1)

Where c_{Rn} is a measured indoor radon concentration, Φ_{Rn} (Bq.s^{-1}) is the radon entry rate; k (s^{-1}) is the ventilation rate and λ (s^{-1}) represents the radon decay constant.

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DEPRESSURIZATION METHOD – BLOWER DOOR DIAGNOSTIC SYSTEM APPLICATION

A designed approach is principally based on the combination of a standard BD measurement technique application, commonly used for energy loss studies and air leakages quantification in civil engineering, with a continuous indoor radon concentration monitoring (Froňka, 2005). The different bulk infiltration parameters under defined BD pressure modes for a single room can be assessed independently on human activities and weather conditions. The convective component of characteristic value of radon entry can be significantly enhanced by the artificially produced pressure difference application. Under given pressure conditions, individual radon pathways can be identified and subsequently quantified as well. With regard to the experimental room volume and overall air tightness, the pressure difference for each single BD test can occur within the interval from approximately 5Pa up to 100Pa. In addition, the BD pressure difference over the whole room envelope is managed to be constant for each single BD measuring mode. Under these circumstances, a characteristic height dependence of naturally ventilated buildings is effectively suppressed. For subsequent quantitative analysis, the artificial ventilation rate k_{BD} can be calculated from the BD fan pressure difference record and the radon entry rate can be assessed from the appropriate radon concentration equilibrium state or by the radon build up curve numerical analysis, described above in detail. The most important BD quantitative characteristics, artificial ventilation rate (standard BD characteristic) and the radon entry rate (radon BD characteristic) as a function of the BD pressure difference, can be derived from the BD experimental results using the appropriate air leakage and infiltration approximations (Cavallo, 1992), (Froňka, 2008).
At first approximation, the BD artificial ventilation rate Q can be expressed as a power function of the BD pressure difference (2).

$$_{BD}Q(\Delta p) = f_{BD} \cdot (\Delta p)^{n_{BD}}$$ Equation (2)

Where $_{BD}Q_{Rn}$ ($m^3.s^{-1}$) is the constant ventilation rate for a defined BD pressure difference Δp (Pa); f_{BD} is the flow coefficient and n_{BD} is the flow exponent.
Analogically, identical regression analysis has been applied for the radon BD characteristic evaluation related to the air infiltration from the subsoil into the indoor environment (3).

$$_{BD}\Phi_{Rn} = f_{Rn} \cdot (\Delta p)^{n_{Rn}}$$ Equation (3)

Where $_{BD}\Phi_{Rn}$ ($Bq.s^{-1}$) is the constant radon entry rate for a defined BD pressure difference Δp (Pa); f_{Rn} is the flow coefficient and n_{Rn} is the flow exponent.

The true value of radon entry rate for natural pressure and temperature field gradients can be estimated from the extrapolation of radon BD characteristic into the low pressure differences region. In respect to individual building component classification, several quantitative infiltration parameters, e.g. the effective leakage area (Froňka, 2005), can be derived from proposed fundamental BD characteristics.

BD infiltration parameters

The quality of radon-proof preventive and remedial measures for separate building compartments can be expressed as a ratio represented by equation (4). The given ratio, BD radon transfer factor, enables to quantify the contribution of air infiltration from the subsoil relatively to overall air infiltration for the single room.

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$$T_{\Delta p} = \frac{_{BD}\Phi_{Rn}(\Delta p)}{c_{soil}} \qquad (4)$$

Where c_{soil} (Bq.m^{-3}) is the characteristic value of soil gas radon concentration
The expression (5) represents a specific value of indoor radon concentration established during the BD depressurization test. The predominant mode of air infiltration phenomenon for a selected BD pressure mode can be determined respectively.

$$c_{stac} = \frac{_{BD}\Phi_{Rn}(\Delta p)}{_{BD}Q(\Delta p)} = \frac{f_{Rn}}{f_{BD}}(\Delta p)^{n_{Rn}-n_{BD}} \qquad (5)$$

In order to observe the very fast indoor radon variations due to specific BD experimental conditions, a unique continuous radon monitor characterized by a very fast response was designed and applied (Froňka, 2004). The detection principle of the new device is based on an airflow ionization chamber operating in the current mode. The fast response of the detector vests in the very fast passage (as high as 30 air exchanges) of the filtered air sample through the detector sensitive volume. This arrangement prevents creation of the radon daughters I the sensitive volume and the signal corresponds namely to the pure radon concentration. The details concerning the RADONIC 01 device can be found at www.radon.eu/radonic.html.

The characteristic radon buildup curve for the constant BD pressure difference (40 Pa) is illustrated in figure 1. The steady state of radon concentration under such pressure field conditions is established within the time period of 45 minutes. In view of these unique measurement properties, in particular the prominent detection response, the application of the continuous radon monitor is evident. In addition, the described device due to the given detection feature can be routinely used for indoor radon specific behavior monitoring with regard to human activities in the building. The characteristic result of such a type of measurement is given in figure 2. In this case, extremely fast indoor radon variations correspond to a cellar door opening, which is responsible for the dominant component of radon entry into the building environment.

Figure 1 Build up curve numerical analysis for the radon diagnostic BD test (40Pa)

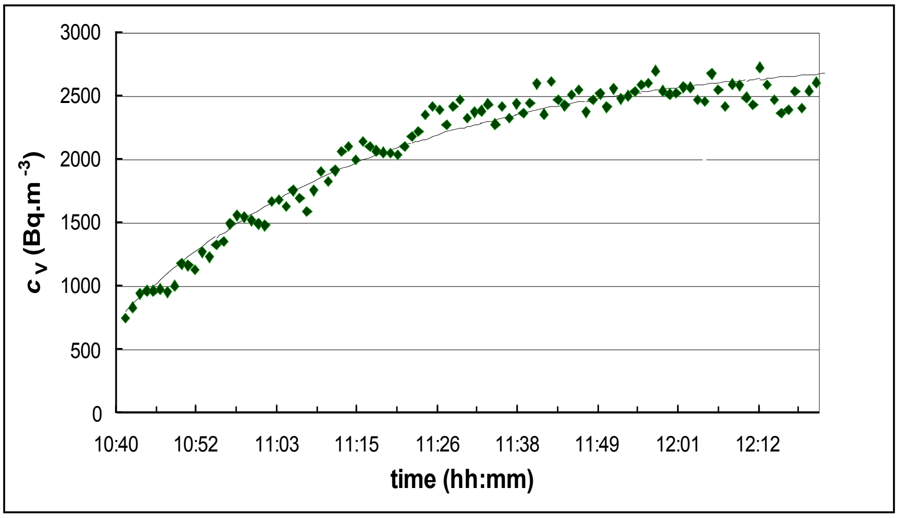

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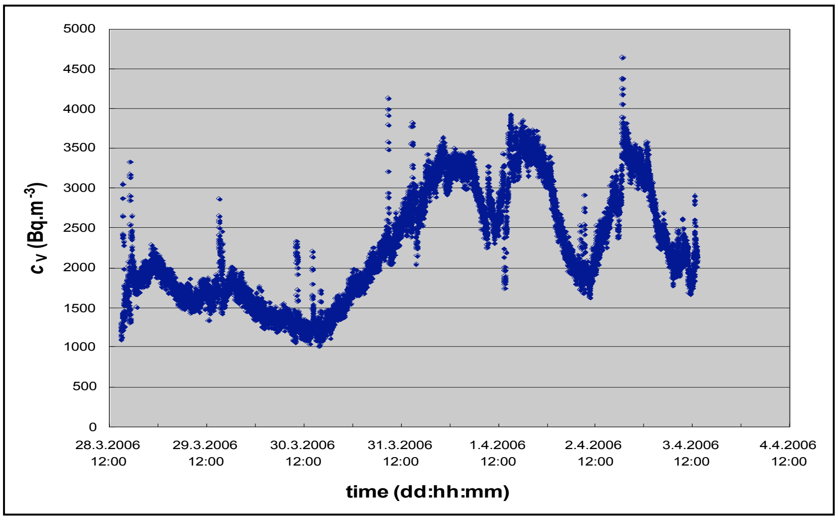
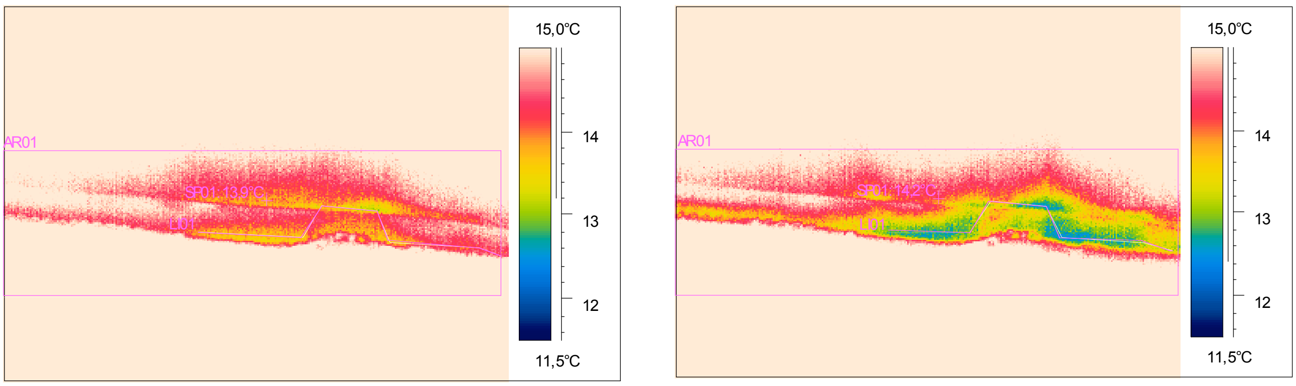
Figure 2 Indoor radon dynamics study using the continuous monitor with fast detection response



INFRARED IMAGING SYSTEM

For the purpose of radon infiltration pathways localization, the infrared imaging system has been tested as a specific radon diagnostic tool. The standard infrared thermography provides the non-contact surface temperature distribution measurements. In fact, the new approach is in particular focused on an identification of cool soil gas penetrating into the indoor environment. Generally, the diagnostic procedure is based on the simultaneous BD diagnostic measurement and the infrared thermography scanning of individual building structures and elements that are in a direct contact with the subsoil. The cold soil gas is driven by the artificial BD pressure gradient into the indoor environment and causes a drop in temperature in the defined leakage area. Characteristic outputs of infrared imaging system application, a set of normalized infrared images for different BD pressure modes, can be seen in the figure 3. The application of the presented diagnostic method has been experimentally verified for radon entry qualitative analysis purposes. On the other hand, the specific method of semi-quantitative thermograms analysis, a defined area integral delineated by an exact isotherm within the leakage area dependence on applied BD pressure level, can be provided as well.

Figure 3 Comparison of normalized infrared images of the defined leakage area for natural pressure field conditions respectively the defined BD pressure modes (17Pa, 32Pa, 50Pa)



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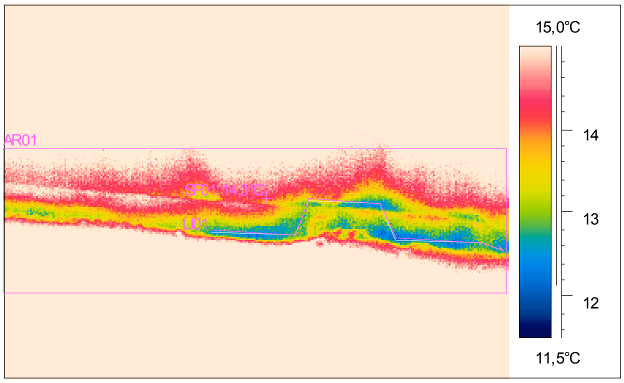
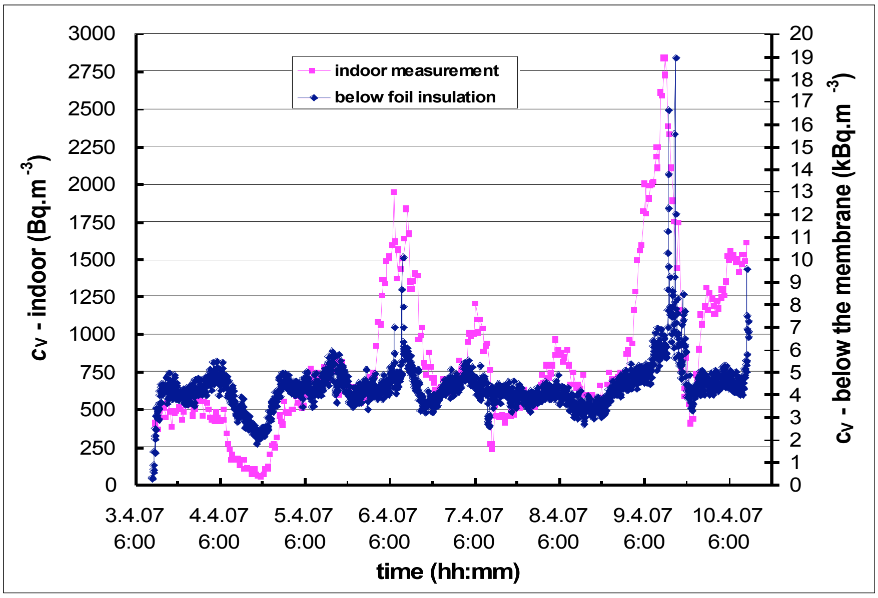
CONTINUOUS SOIL GAS RADON MONITORING

In view of design of radon-proof preventive and remedial measures, the radon potential assessment has to be involved into the radon diagnostic system. The knowledge of soil gas radon concentration and soil permeability depth profiles in the vicinity of investigated buildings is essential (Neznal, 2004) due to the subsoil physical properties modification related to a terrain adjustment of the former building site. For the purpose of instantaneous soil gas radon time variations measurement, the new continuous radon monitor has been developed and tested (Froňka, 2008). Simultaneous indoor radon concentration measurement and soil gas radon monitoring enables the instantaneous values of radon transfer factor assessment. In this context, specific human indoor activities resulting in indoor and soil gas radon fluctuations can be observed and investigated in connection with pressure and temperature field gradients. The unique experimental result, a chart of indoor and soil



gas simultaneous continuous measurement in a typical family house with ineffective radon-proof measure, is given in figure 4.

Figure 4 Result of simultaneous continuous soil-gas and indoor radon concentration measurements – soil gas sampling probe placed in the gap at joint (air filled layer) between the subsoil and a damp-proof membrane



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TRACER GAS MEASUREMENT

For the purpose of an independent air-exchange rate estimation and related radon entry rate analysis, the common tracer gas method using the carbon monoxide as a primary tracer gas has been applied. In addition, a specific mathematical approach based on a state-space dynamic statistical model has been used for experimental data analysis (Jílek, 2007). A simultaneous monitoring of indoor radon concentration and carbon monoxide concentration enables the radon entry rate and the ventilation rate separate assessment for the assumed single zone approximation. Results of tracer gas measurement can be compared with outputs of radon build up curve numerical analysis. Described diagnostic procedure can be routinely applied for the individual room air-exchange rate enhancement related to active depressurization system operation providing an effective radon removal from the subsoil. In addition, the method of the independent air-exchange rate assessment has been applied to reliably reveal the main cause of high level of indoor radon occurrence in new buildings or building under construction. In several cases of radon diagnosis measurements, the extremely low air-exchange rate, below the level of $0.05h^{-1}$, has been identified as the major cause of high radon concentration presence in the building environment.

CONCLUSIONS

A complex set of radon diagnostic procedures, including a unique detection system development and specific theoretical approaches for experimental data analysis application, has been proposed and tested in the field under various experimental conditions. The special blower door diagnostic method, pointed out in this paper, provides the stable experimental conditions for the indoor radon concentration measurement independent on weather conditions and human activities in the building.

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