The Effect of New Building Concepts on Indoor Radon

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Abstract

The building sector is at present responsible for more than 40% of EU energy consumption. New technologies have been implemented in new houses and are continually under development, which substantially improve the energy performance in buildings, reducing the conventional energy demand in new and existing buildings. New building concepts all aim at a new approach for the design, construction and operation of new and/or refurbished buildings in order to reach a high level of energy efficiency and sustainability. Various terms exist for those building concepts like green building, low energy house, passive house, triple zero house, eco-building, etc.

Within the EU-project RADPAR the effect of such new building concepts on indoor radon levels were investigated in detail. First, the construction, heating, and ventilation technologies used in modern dwellings were identified and subsequently their potential effect on indoor radon was assessed. To complement and to verify the findings a survey in 28 passive houses in radon prone areas in Austria was conducted. In another 9 passive houses more detailed radon measurements were made by means of active devices. In general, the results were below 300 Bq/m³, in the majority of houses even below 100 Bq/m³. However, in a few houses high radon concentrations were found.

The main results of this study are: (i) the high standard of airtightness of the building shell of new buildings is basically beneficial with respect to low radon levels, (ii) controlled mechanical ventilation has principally a positive effect on radon indoors, (iii) however, certain design features or bad practice may cause high radon levels, e.g. leaky earth tubes of ground-coupled heat exchangers, improper sealing of penetrations of geothermal heat pumps, switching off mechanical ventilation in summer, use of air wells for preheating of outside air.

As a result of this study, recommendations were set up to avoid any adverse effect of these new technologies on indoor radon levels.

Key Words: radon, energy efficient buildings, passive houses

1. Introduction

The planning of an energy efficient house relies on two principal goals (Krapmeier 2001):

- optimising the basic requirements (building shell, windows, doors, automatic ventilation)
- loss minimisation before gain maximisation (minimise transmission and ventilation losses, air tight building shell)

The building shell of a such a house features very high compactness, insulation standard, and air tightness. Often, a mechanically controlled ventilation system is installed to minimise energy losses through uncontrolled air exchange. It assures the thermal conditioning of the rooms and simultaneously constantly supplies the building with sufficient fresh air. A passive preheating stage via a geothermal heat exchanger as well as an air/air heat exchanger are typical features of a highly efficient ventilation system (see Fig. 1).

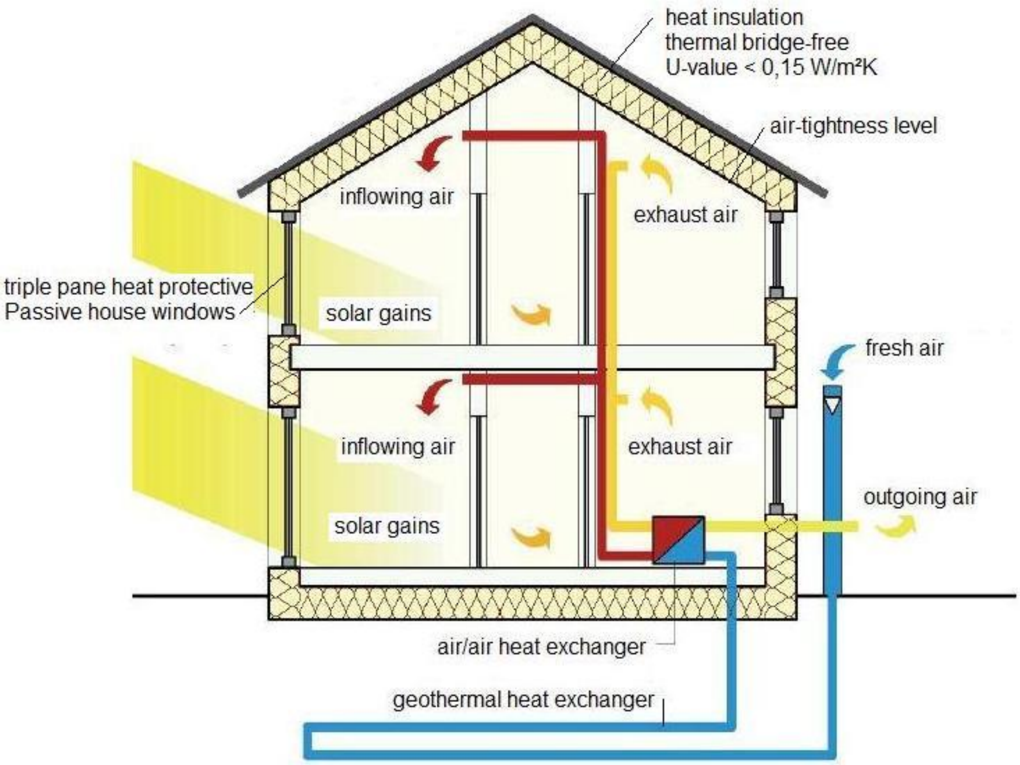

Figure 1: Basic principle of passive houses (PHI 2009, online; edited)

Various terms are used for energy efficient buildings (Erhorn 2010):

- Bioclimatic House	- Passive house
- BREEAM Building	- Plus Energy House
- Carbon Free House	- TBQ: Total Quality Planning and rating
- Climate: Active House	- Triple Zero House
- CSH: Code for Sustainable Homes	- Ultra Low energy House
- Eco-Building	- Very Low Energy House
- Emission Free House	- Zero Carbon house
- Energy Saving House	- Zero Emission House
- Energy Self-Sufficient House / Energy Autark House	- Zero Energy House
- Green building	- Zero Heating Energy House
- Lider A	- 3 - Liter House
- Low Energy House	

New building concepts often apply new and innovative technologies with respect to construction, heating, and ventilation. The effect of those technologies on other important issues like indoor air quality needs to be analysed.

One important indoor air contaminant is the radioactive noble gas radon. Building-specific factors like cracks, fissures, holes, etc. in the building foundations, pressure differentials across the building shell (stack effect) acting as driving forces for convective radon entry from the ground, and the ventilation rates control the indoor radon level (in association with soil radon concentration in and soil permeability beneath the building).

Within the EU-project RADPAR (RADPAR 2009-2012) the effect of new construction, heating, and ventilation technologies specific to energy efficient buildings on indoor radon has been studied. This paper is based on the following reports which are all part of *Deliverable 13 – Assessment of potential conflicts between energy efficient buildings and radon exposure*:

D13/2 – Questionnaires: Compilation and Assessment
D13/3 – Survey of Construction Technologies in Low Energy and Passive Houses in Europe
D13/4 – Heating and Ventilation Systems in Low Energy and Passive Houses in Europe
D13/5 – Measurement and Analysis of Radon in Selected Passive Houses in Austria
D13/6 – Review of low energy construction, airtightness, pressure conditions and indoor radon in Finnish residential buildings
D13/7 – Radon and Energy Efficient Constructions: Assessment and Recommendations

2. Compilation and Assessment of Questionnaire

At the beginning of the study a questionnaire had been sent to the member states to inquire about regulations or guidelines dealing jointly with energy saving construction and indoor air quality / indoor radon exposure, studies to estimate the effect of low energy construction technologies on indoor radon, and about specific building labels with respect to energy saving construction and indoor radon exposure.

25 countries replied and the following main conclusions can be drawn:

- Whereas in the majority of the countries regulations or guidelines dealing jointly with energy saving construction and indoor air quality exist, there is only in Switzerland a specific recommendation for energy saving construction and radon
- Only in Switzerland studies have been conducted so far to investigate radon levels in passive houses
- Several countries replied that studies to estimate the effect of low energy construction technologies on indoor radon are either under development, in progress, or under consideration showing that there is increasing interest in this subject
- Only in Switzerland, France, and Portugal a label for new buildings exists where the radon issue is included; however, there are differences in the radon target level and whether the radon requirement is voluntary or compulsory

3. Measurement and Analysis of Radon in Selected Passive Houses in Austria

Radon measurements were carried out in 37 low energy and passive houses to assess the impact of construction, heating, and ventilation technologies specific to energy efficient buildings on indoor radon.

Both long-term passive and active radon measurements were conducted; in some houses also building airtightness and CO_2 measurements were made.

3.1. Radon Screening of Passive Houses in Radon Prone Areas

For the screening measurements with track-etch detectors 28 passive houses (mean n50-value of 0.33 1/h) were selected, all of them in communities in radon prone areas of the highest radon potential class. Measurements were carried out in the two most occupied rooms of the dwellings for a period of at least two months. In Figure 2 the radon results are given for all dwellings.

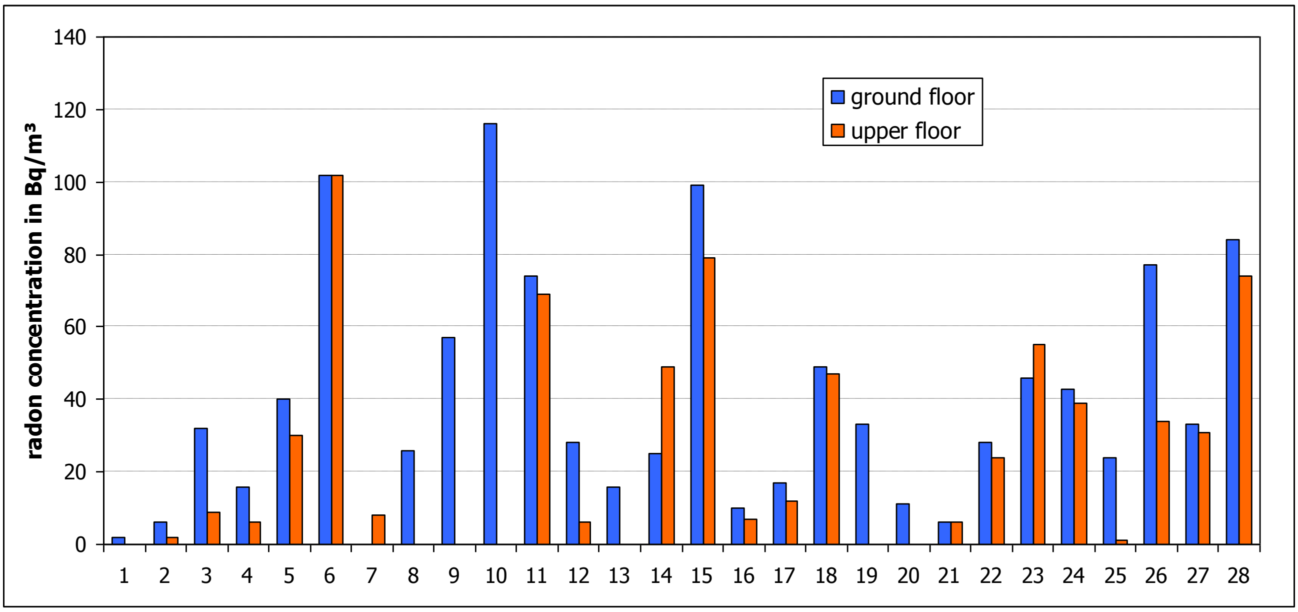

Figure 2: Results of radon measurements in 28 passive houses in areas of the highest radon potential class in Austria

The main results can be summarised as:

Mean value of all houses mean values:	34 ± 28 Bq/m³
Mean value of ground floors:	39 ± 32 Bq/m³
Mean value of upper floors:	31 ± 30 Bq/m³
Highest value measured:	116 ± 16 Bq/m³

To summarise, long-term radon measurements in 28 passive houses – all of them located in communities in radon prone areas of the highest radon potential class – yield very low levels (even when taking into account that the annual mean radon concentration is probably by a factor of approx. 1.5 higher as the measurements were conducted in spring time). Similar results were obtained in Switzerland (Roserens 2010) and Germany (Bergmann 2006).

3.2. Detailed Radon, Airtightness and CO2 Measurements in Selected Low Energy and Passive Houses

Nine low energy and passive houses in Upper Austria were investigated. The radon concentration was measured with three active devices per building. For four houses the air tightness was evaluated by the Blower Door test and CO_2 concentration, air pressure and relative humidity were logged. During the measurement period, the ventilation system was shut off several times to evaluate the effect of ventilation on the indoor radon (and CO_2 concentration).

The main findings can be summarised as:

<u>Ventilation ON/OFF</u>

Turning off the mechanical ventilation systems leads to an 6- to 10-fold increase in radon level depending on the geogenic radon potential, leakage area in the foundations and location of the measured room (see Figure 3).

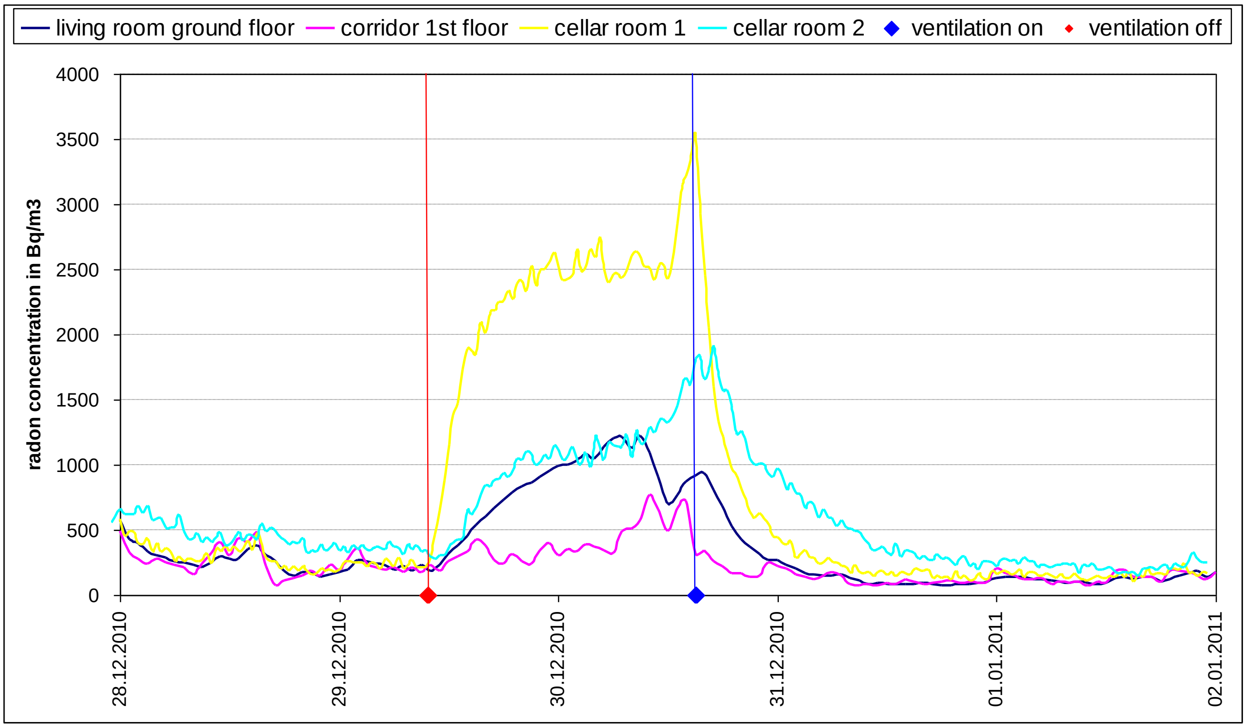

Figure 3: Effect of turning off the mechanical ventilation system on the radon level in different rooms

<u>Individual room not included in the mechanical ventilation system</u>

If a room is not included in the mechanical ventilation system but is inside the thermal envelope the radon level in this room is not or only slightly higher than in the ventilated rooms. However, if that room is outside the thermal envelope a moderately to substantially higher radon level could be observed (see example in Figure 4).

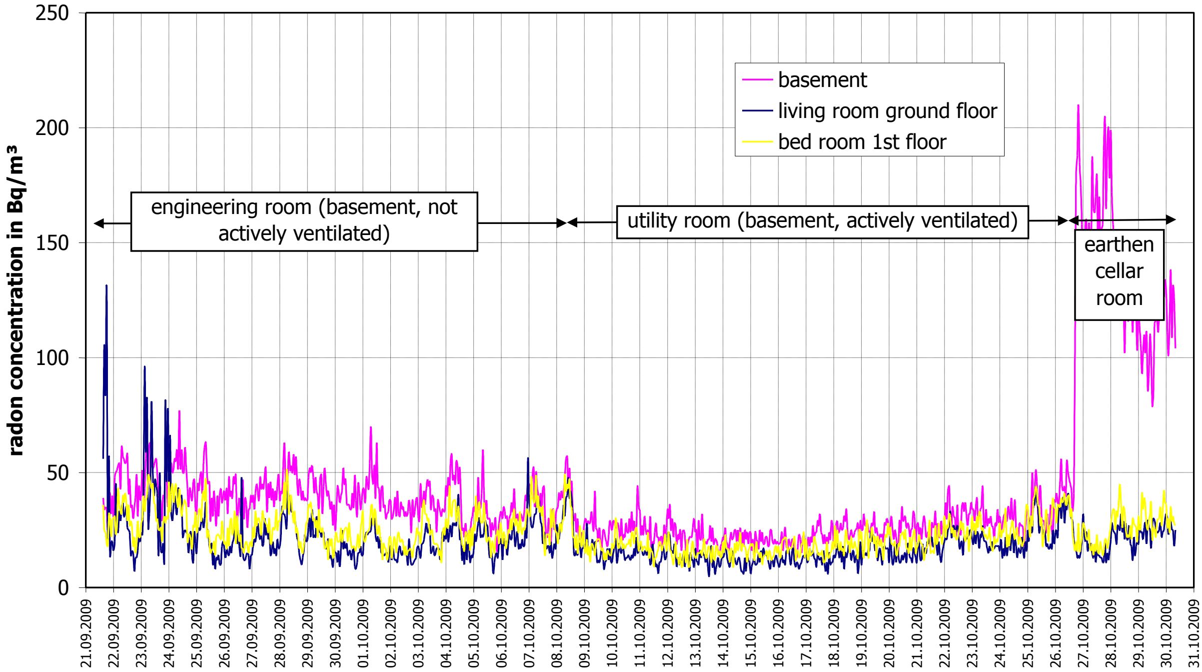

Figure 4: Example of higher radon level in room not included in the mechanical ventilation system and outside the thermal envelope

<u>Ground-coupled heat exchanger with concrete / plastic earth tubes</u>

During the construction of a low energy dwelling both concrete and plastic earth tubes were installed in parallel in the ground to test the effect of tube material on the indoor radon concentration (see Figure 5).

Figure 5: Installation of concrete and plastic earth tubes in the ground

The assessment of the measurement data leads to the following conclusions:

(a) the radon concentration in the ventilated rooms is by a factor of about 1.5 higher when the air supply is through the concrete earth tubes instead through the plastic earth tubes

(b) this ratio increases to about 2.0 if an additional filter is placed at the air intake indicating that due to the higher underpressure in the earth tubes relatively more soil gas enters the concrete earth tubes than the plastic earth tubes through leakages

(c) in general, placing an additional filter on the air intake increases the indoor radon concentration; two different mechanisms may cause that increase: (i) the entry rate of soil gas into the earth tubes increases due to the higher underpressure in the earth tubes, (ii) an increasing dust load on the filter reduces the supply air rate and thus increases radon concentrations; it is not possible to separate these two mechanisms as the air exchange rates were not determined during the various conditions; however, the ratio of radon concentrations with/without additional filter increases stronger for concrete earth tubes (approx. 2.8) as for plastic earth tubes (approx. 2.0) which agrees with (a) and (b) and confirms that the concrete earth tubes are less air-tight than the plastic earth tubes

4. Assessment and Recommendations

As has been shown in the previous chapter, basically, the combination of a highly airtight building envelope and a controlled mechanical ventilation system leads to very low indoor radon levels. Nevertheless, certain features of the new technologies may cause high radon levels. The assessment of the relevance of design and construction features of energy efficient buildings with respect to indoor radon led to a number of recommendations.
In the framework of the RADPAR project, they have been categorised into recommendations with respect to construction technologies, heating and ventilation systems. Four selected recommendations are given below:

- With respect to radon the airtightness of the foundation is the key factor. It is recommended to include the basement in the thermal envelope. If this is not wanted, then the walls and floor of the basement have to incorporate radon preventive measures according to the requirements for new buildings which are available in most EU countries. A radon measurement for verification is recommended.

- It is recommended to use plastics as material for the earth tubes (PP, PE, PVC). Concrete tubes should not be used (high porosity, leaky connections).

- Earth tubes can consist of one single, flexible tube or of several rigid tubes which need to be connected. If the earth tubes consist of several tubes then it has to be made sure that the fittings are airtight, e.g. by using welded fittings.

- Radon entry from the ground through drainage openings can be avoided by
  - using a siphon
  - pumping the condensate from an airtight pump sump into a wastewater pipe of the building (see Figure 6).

  When using a siphon then the siphon must not dry out at any time. Alternatively, the condensate may be pumped outdoors through an inspection tube.

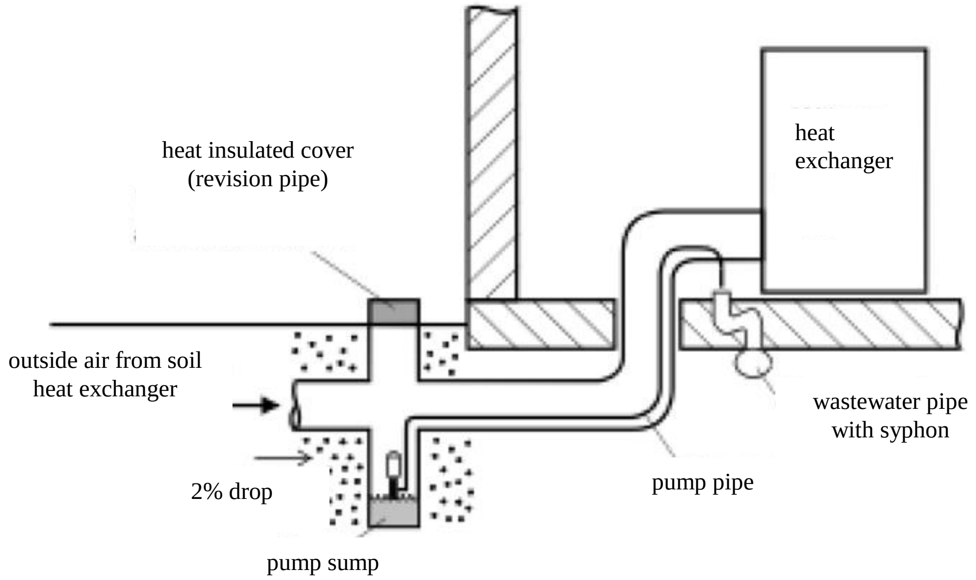

Figure 6: Condensate pipe with submersible pump in pump sump (Paul, 2008, edited)

- It is recommended not to use air wells (see Figure 7) at all.

  Solutions – using a membrane and a siphon – exist which should prevent radon from the surrounding soil to enter the air well (Figure 8). However, the membrane may get leaky or the siphon may dry out. Furthermore, radon exhaled from the filling material is still drawn into the building.

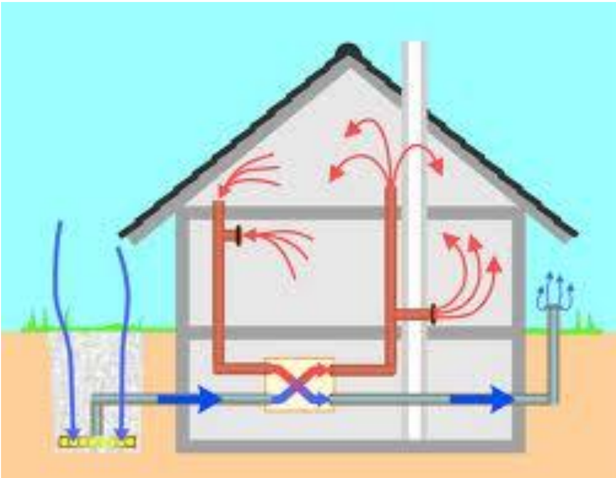

Figure 7: Graph showing the principle of an air well

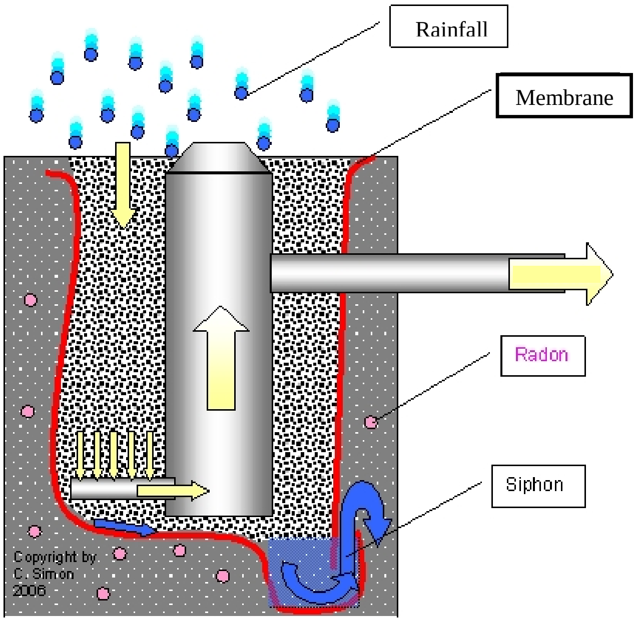

Figure 8: Prevention of radon entry from the soil into an air well (Simon 2011)

5. Conclusions

Measurements in passive houses within this project, in Switzerland, and in Germany (Roserens 2010, Bergmann 2006) yield in general indoor radon concentrations below 100 Bq/m³ even in radon prone areas. All investigated buildings had not been built incorporating radon preventive measures but the floor has been built to be highly airtight to meet the passive house criteria. This provides a barrier providing a high degree of radon protection (similar to a well constructed radon barrier). With the mechanical ventilation system radon reduction is further improved.

Nevertheless, certain features of the new technologies may cause high radon levels. Examples are leaky earth tubes of ground-coupled heat exchangers or bad design of air intakes (e.g. air wells). Proper maintenance of the ventilation systems is also a critical point. The assessment of the relevance to radon of design and construction features of energy efficient buildings led to a number of recommendations which are meant to help building professionals and occupants to plan and build energy efficient homes with very low indoor radon levels. Verification of the indoor radon concentration by radon measurements is strongly recommended in any case. Radon measurements should be repeated after substantial modifications to the building or ventilation system.

Radon measurements may also serve as a tool of quality control for the building and ventilation system (Bergmann 2006). For example, properly sealed earth tubes from a ground-coupled heat exchanger, a deterioration of the airtightness of penetrations through the foundations as well as the general airtightness of the foundations (creation of microfissures due to settlement, alterations by the occupants), and pressure imbalances may be detected through the measurement of the indoor radon concentration. Therefore, radon measurements may provide a tool for verification of the functionality of energy efficient buildings (in particular in areas with high geogenic radon potential).

Having identified potential adverse effects of energy efficient buildings with respect to radon and having set up a number of recommendations to avoid such adverse effects, the next step must be to inform the relevant consultants, manufacturers, and building professionals as well as the public on this issue. Appropriate information material (brochures, WWW, etc.) has to be compiled and published.

It has to be noted that when applying passive house techniques to existing houses where the existing floor does not include radon protection it will prove difficult to seal properly across the full footprint of the building. Therefore, it is difficult to predict the effect of applying passive house techniques to existing houses as on one hand sealing the building shell except the full footprint of the building tends to increase the radon level and on the other hand a mechanical ventilation system decreases the radon level. In any case, a radon measurement must be performed to assess the impact of the retrofitting on the radon level.

Acknowledgment

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