

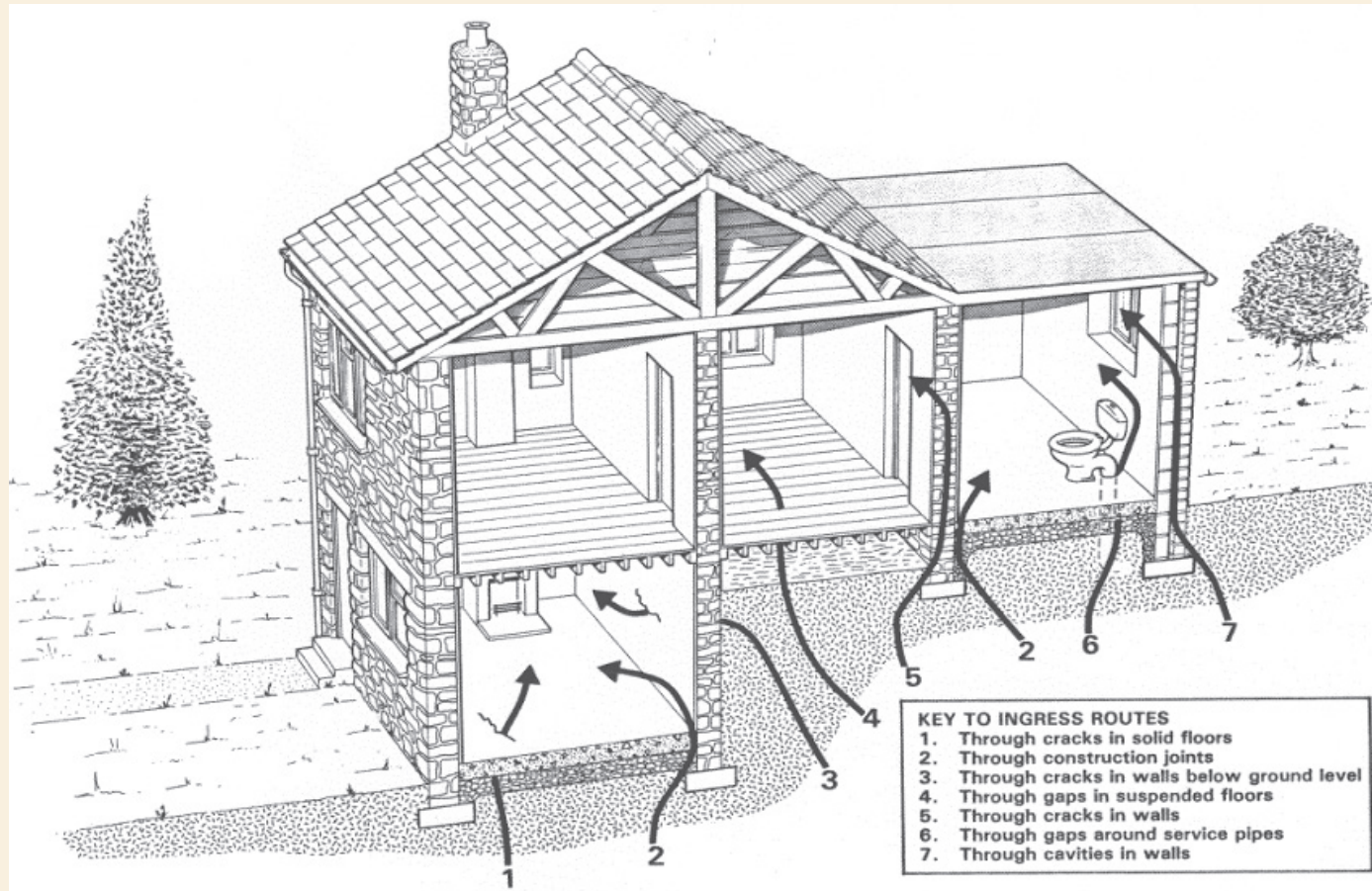
WORKSHOP ON THE CONTROL OF PUBLIC EXPOSURE IN COMPLIANCE WITH THE  
INTERNATIONAL BASIC SAFETY STANDARDS  
Cape town 5-7 May 2016

# **Building codes and corrective actions**

Martin Jiránek  
CZECH TECHNICAL UNIVERSITY, Praha

Jiří Hůlka,  
SURO, Praha

corrective actions are active or passive



*Indoor – lower pressure then outooor!*

# CONTENT

1. Purpose of corrective actions
2. Factors influencing the design
3. Principles of corrective actions
  - *Sealing of radon entry routes*
  - *Ensuring air-tightness of the substructure*
  - *Sub-slab depressurization*
  - *Air gap depressurization*
  - *Measures for houses on crawl spaces/cellars*
  - *Ventilation measures*
4. Rules for selecting corrective actions
5. Thermal retrofitting and indoor radon
6. RADIUM-RICH BUILDING MATERIALS

# 1. PURPOSE OF CORRECTIVE ACTIONS

*..... to ensure that radon in every room of the habitable space decreases below the reference level or design value + ALARA*

**Reference level** is prescribed by legislation within the range

**100 – 300 Bq/m<sup>3</sup>.**

**Design value** is prescribed by the owner

*(determined for example on the basis of ALARA principle).*

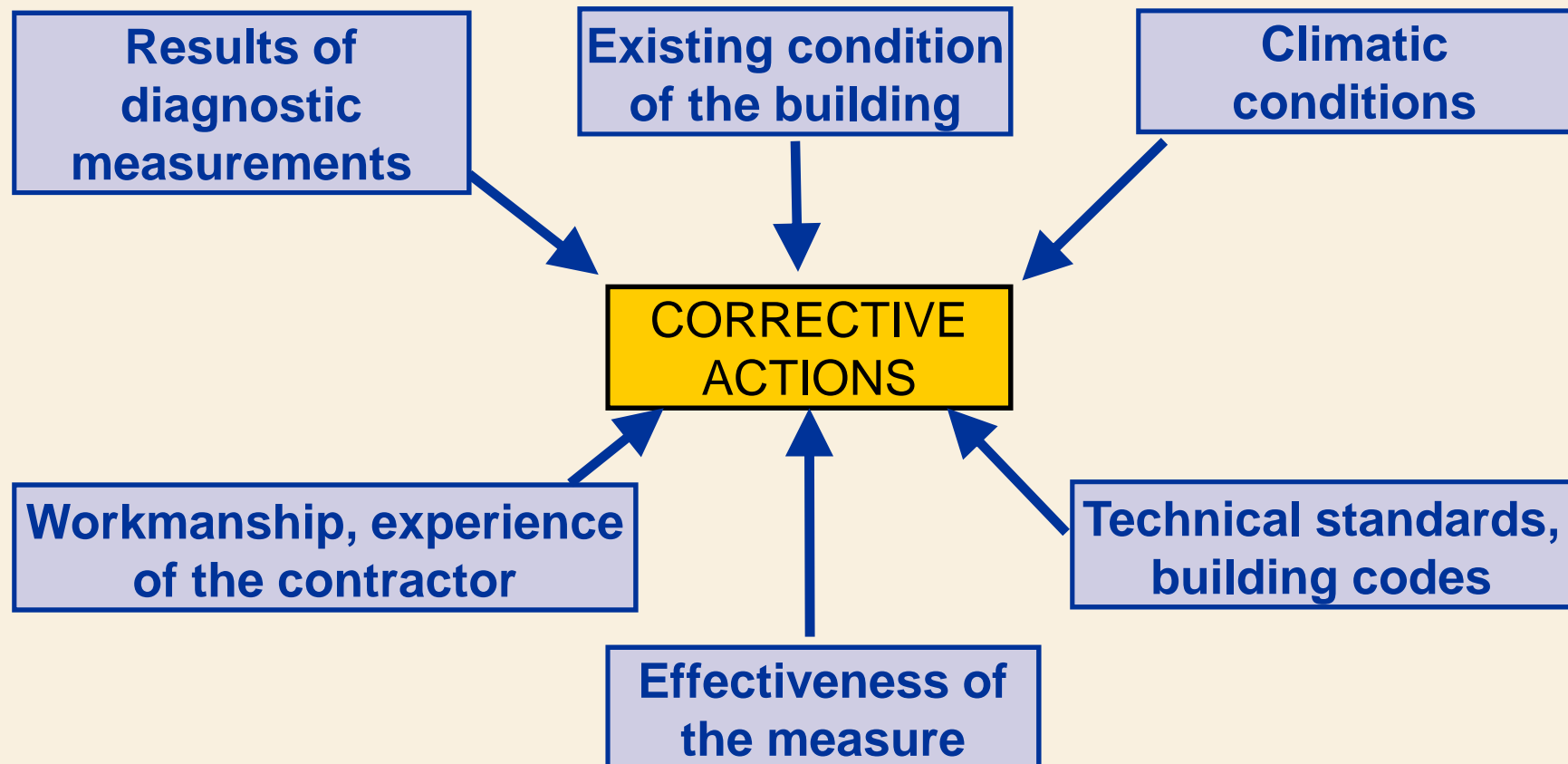
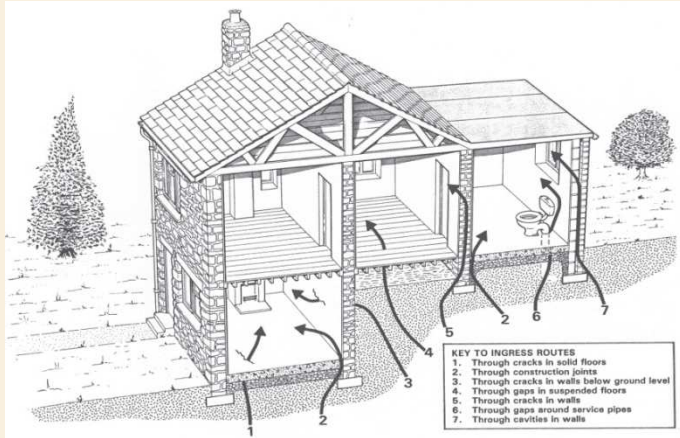
## REMARK:

For new buildings – it is much easier and cheaper to reach low Rn

Strategy: introduce building codes for new building and enforce Rn prevention!

For existing buildings – more complicated to do it !!!

## 2. FACTORS INFLUENCING THE DESIGN



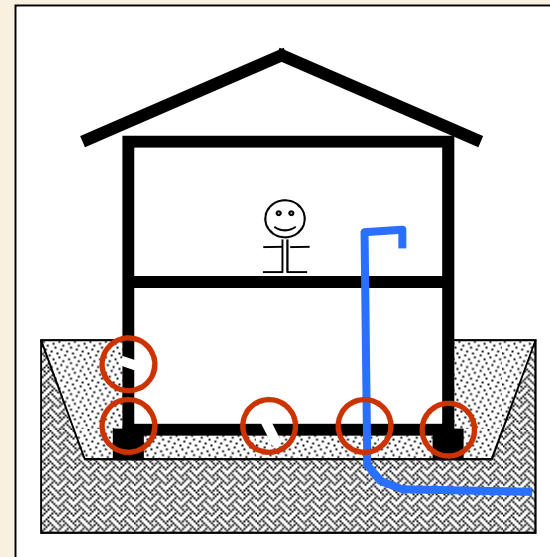
# 3. PRINCIPLES OF CORRECTIVE ACTIONS

## 3.1 Sealing of radon entry routes

Sealing is usually applied for:

- cracks in contact structures
- services penetrations
- gaps between walls and floors

This method is often used in combination with other methods.



Effectiveness is usually lower than 40 %!! + durability (?)

## Sealing of cracks

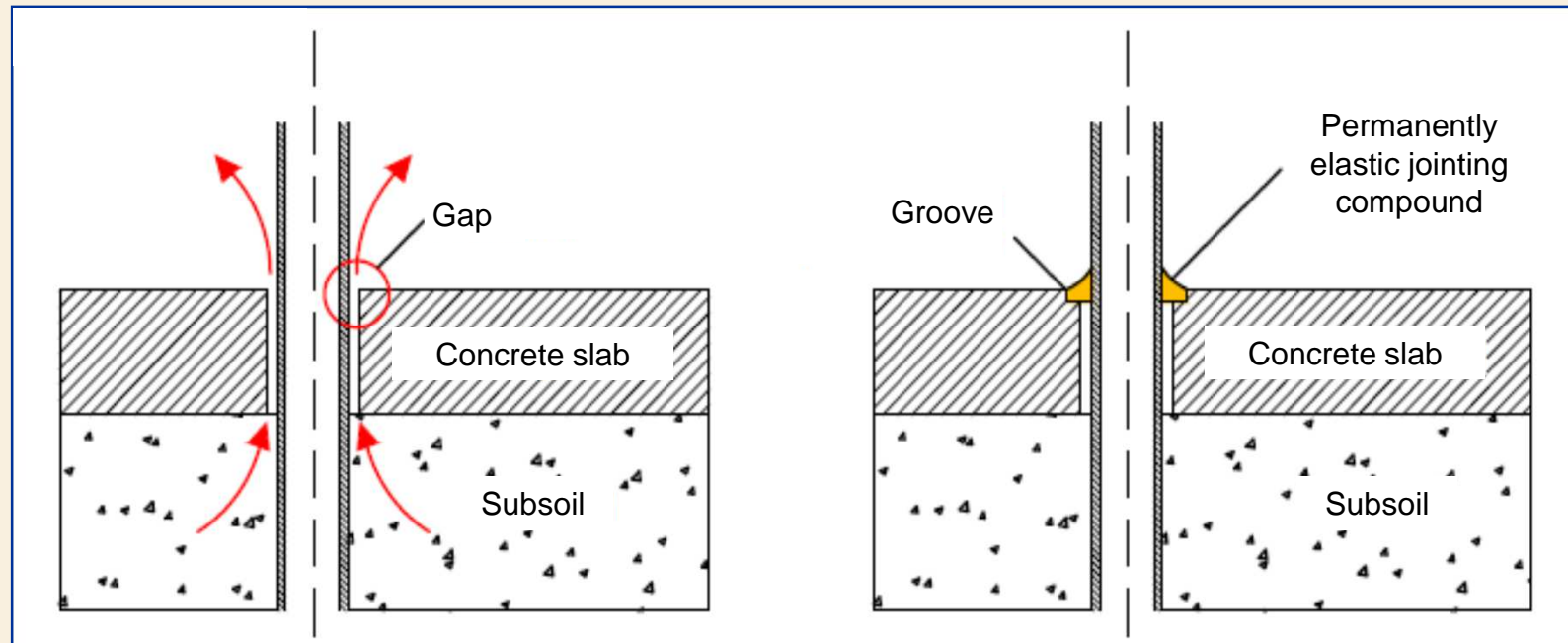
**Passive cracks** (without any movement) – polymercement mortars and compounds, epoxy resins, etc.

**Active cracks** (dilatation movements can occur in the crack) – permanently elastic sealants (acrylic, silicone, bitumen) and PU foams.



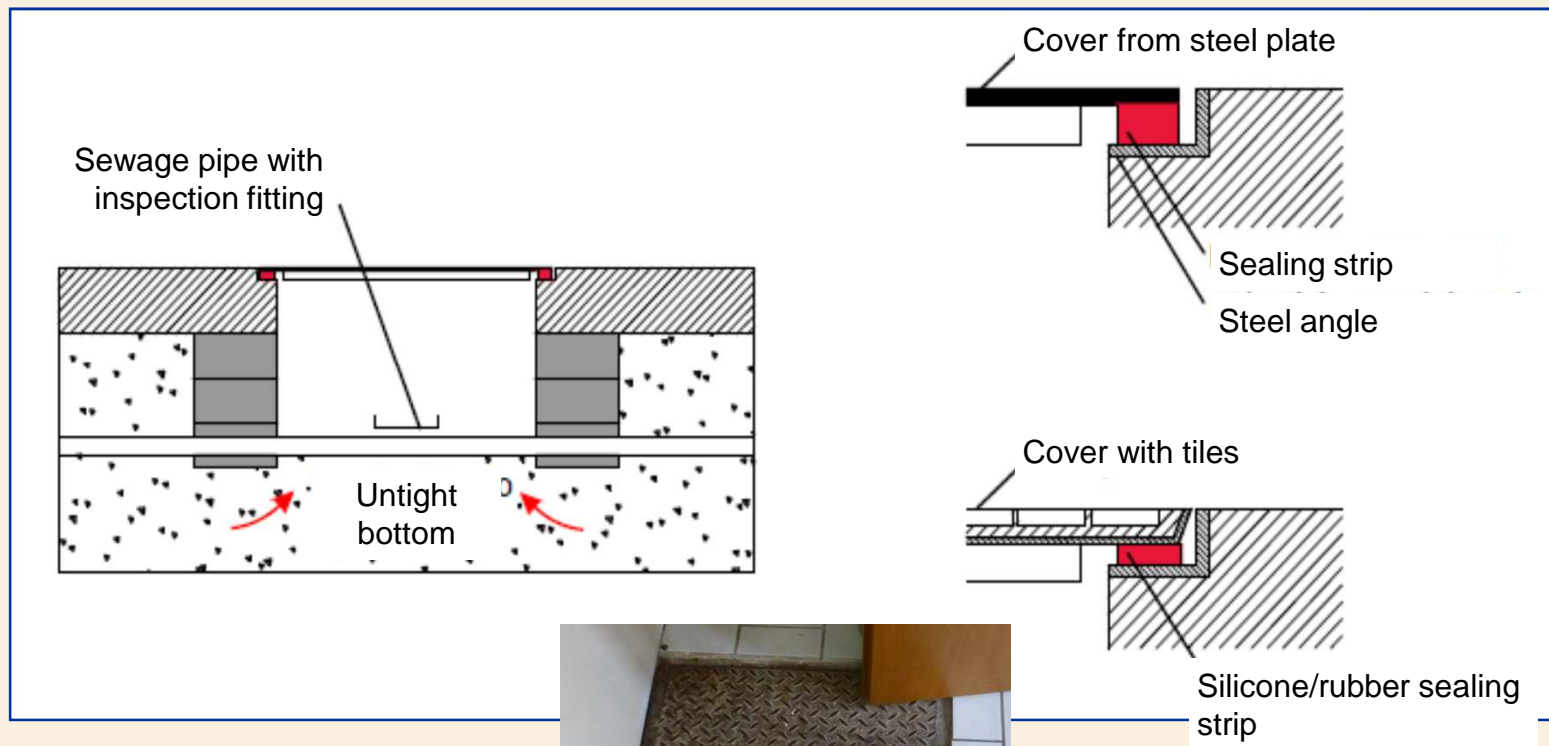
# Sealing of pipe penetrations

## Penetrations without dilatation movements

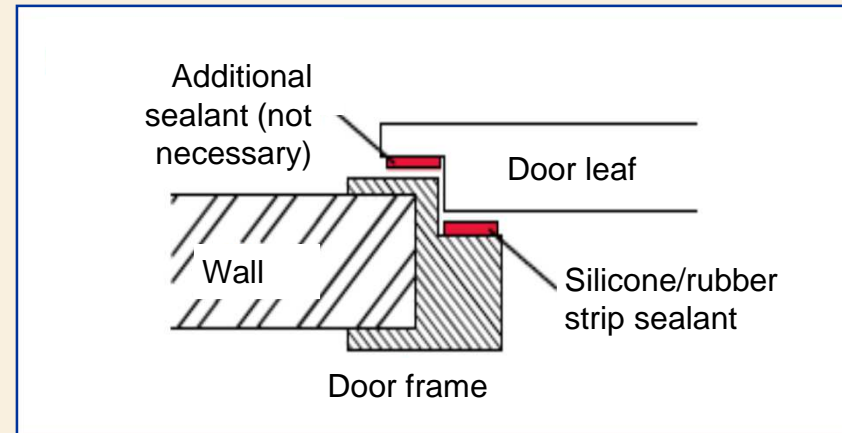
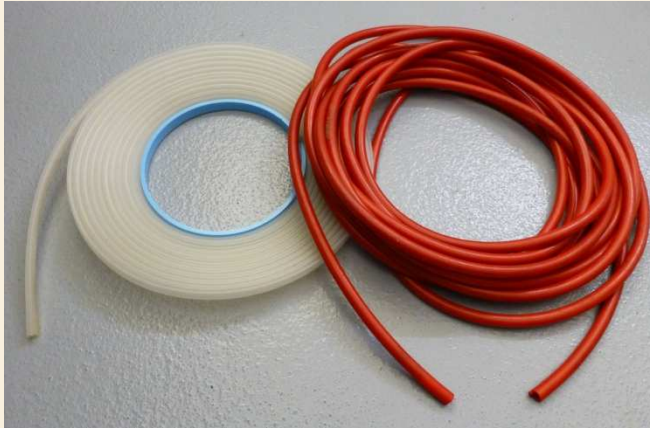




# Sealing of covers of inspection chambers

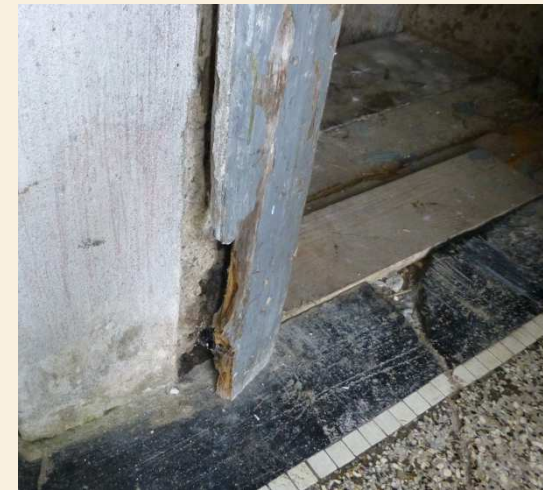


# Sealing of doors to the cellar



Rotten and disintegrated door frames and sills and twisted doors must be replaced with new ones.

Doorsills can reduce air leakage beneath the door.



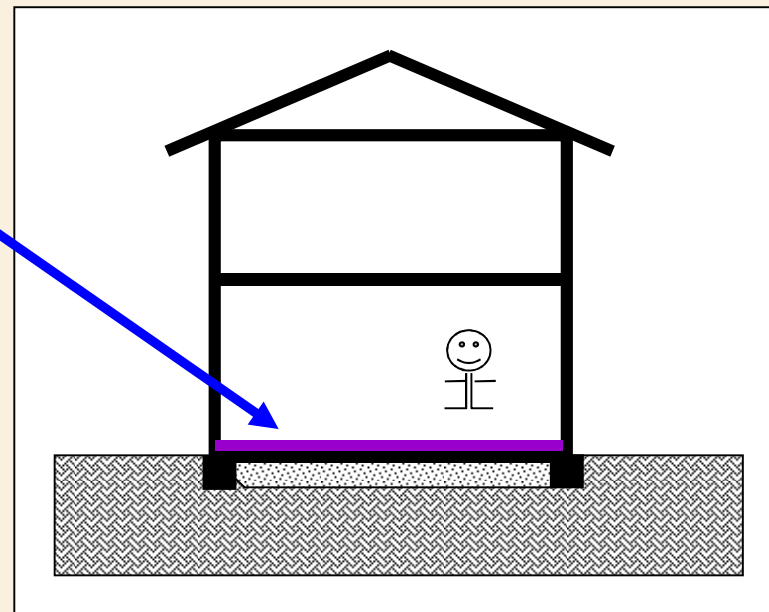
# 3. PRINCIPLES OF CORRECTIVE ACTIONS

## 3.2 Ensuring air-tightness of the substructure

It is **usually not possible** to place radon barrier material continuously over the entire surfaces of walls and floors in contact with the soil

Effectiveness is usually lower than 45 %!

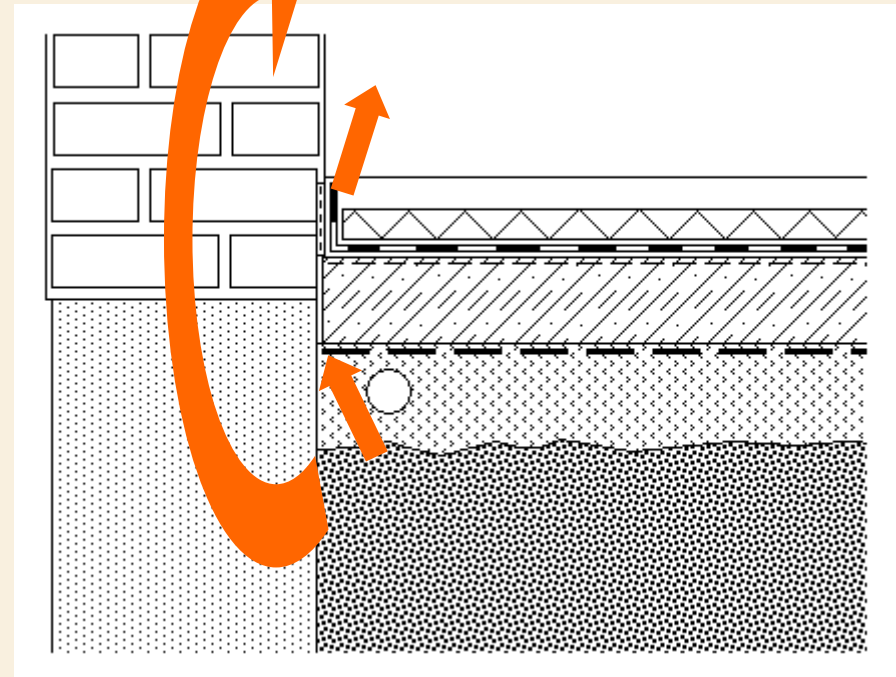
Use only if the reconstruction of floors is necessary due to their bad technical condition.



It is recommended to use this measure in combination with sub-slab or air gap depressurization!

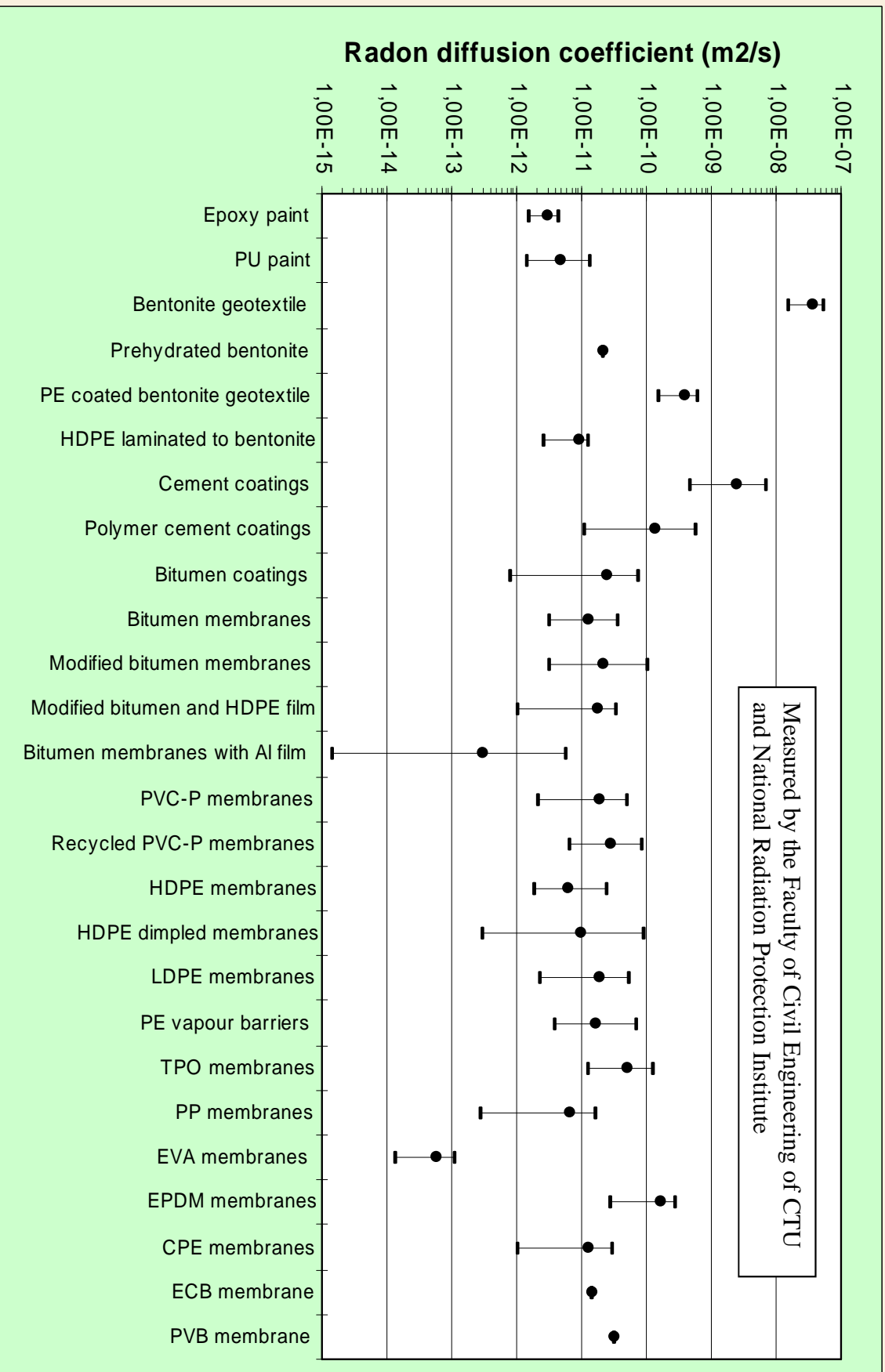
## Additionally applied radon-proof insulation

In existing houses not so effective (less than 45 %), because it usually cannot be applied under the walls and thus radon can be still transported through wall-floor joints. Therefore combination with a soil ventilation system is recommended.



Additionally applied RPI must be connected in an air-tight manner to the existing waterproofing below the walls

# Different radon barriers : summary of measurements of radon diffusion coefficient



# 3. PRINCIPLES OF CORRECTIVE ACTIONS

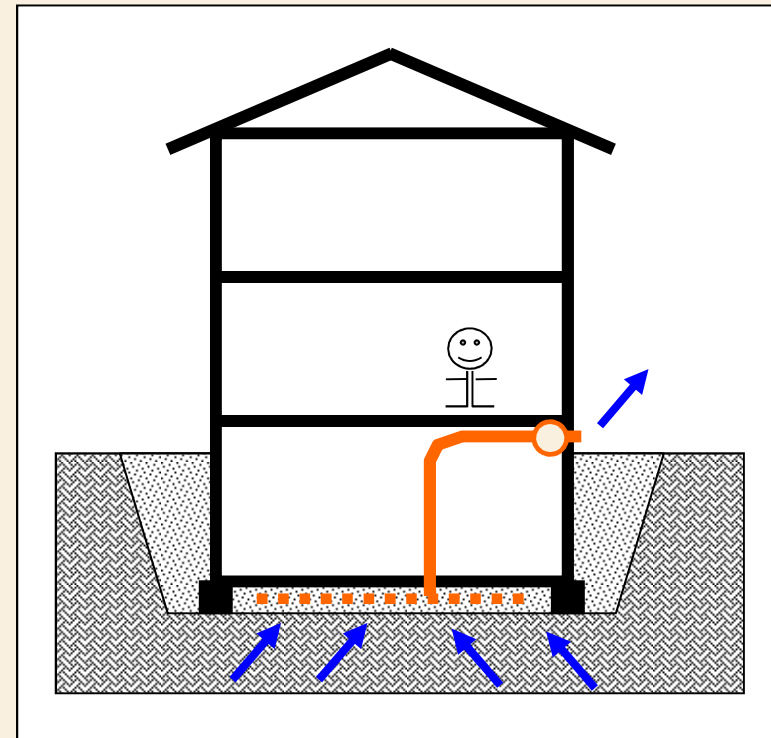
## 3.3 Creating underpressure in the subsoil

Can be ensured by:

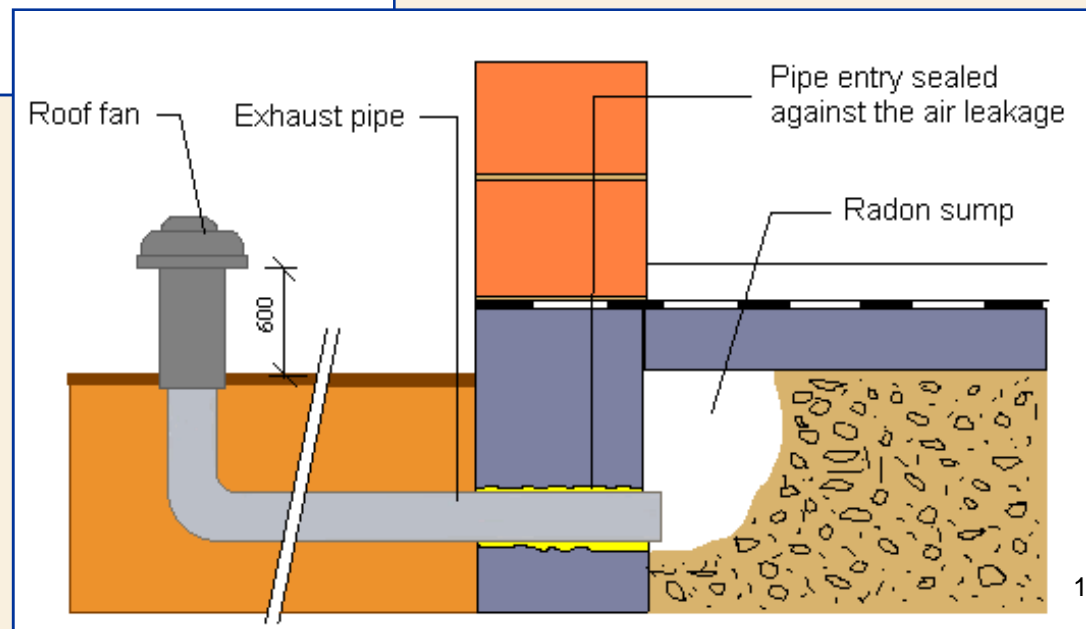
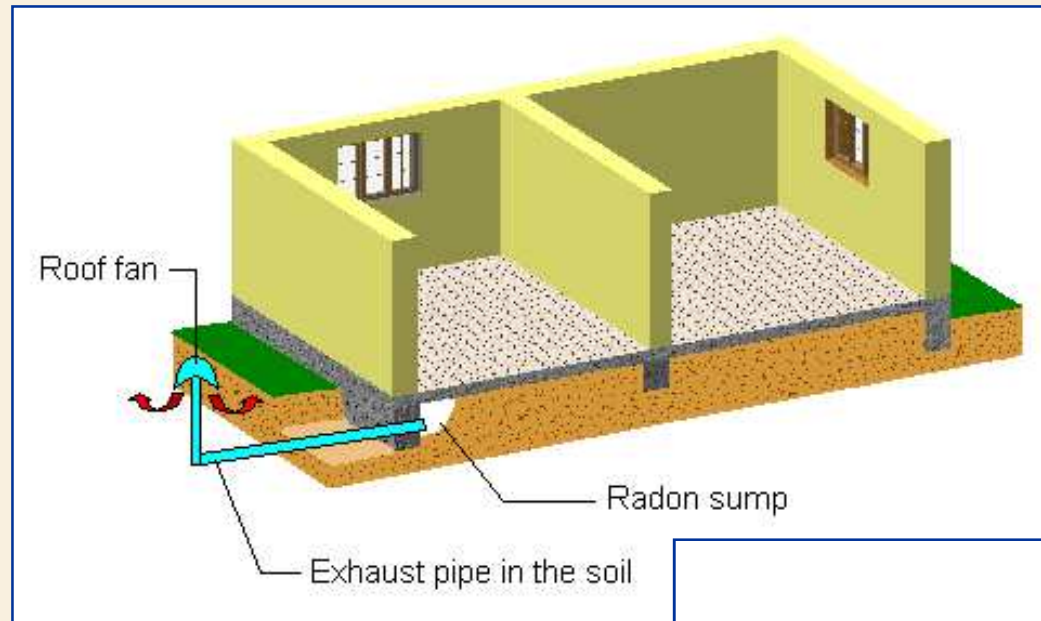
- radon sumps
- drilled tubes
- perforated pipes
- radon well

The preference should be given to systems that can be installed without the reconstruction of floors.

Effectiveness is around 95 %.

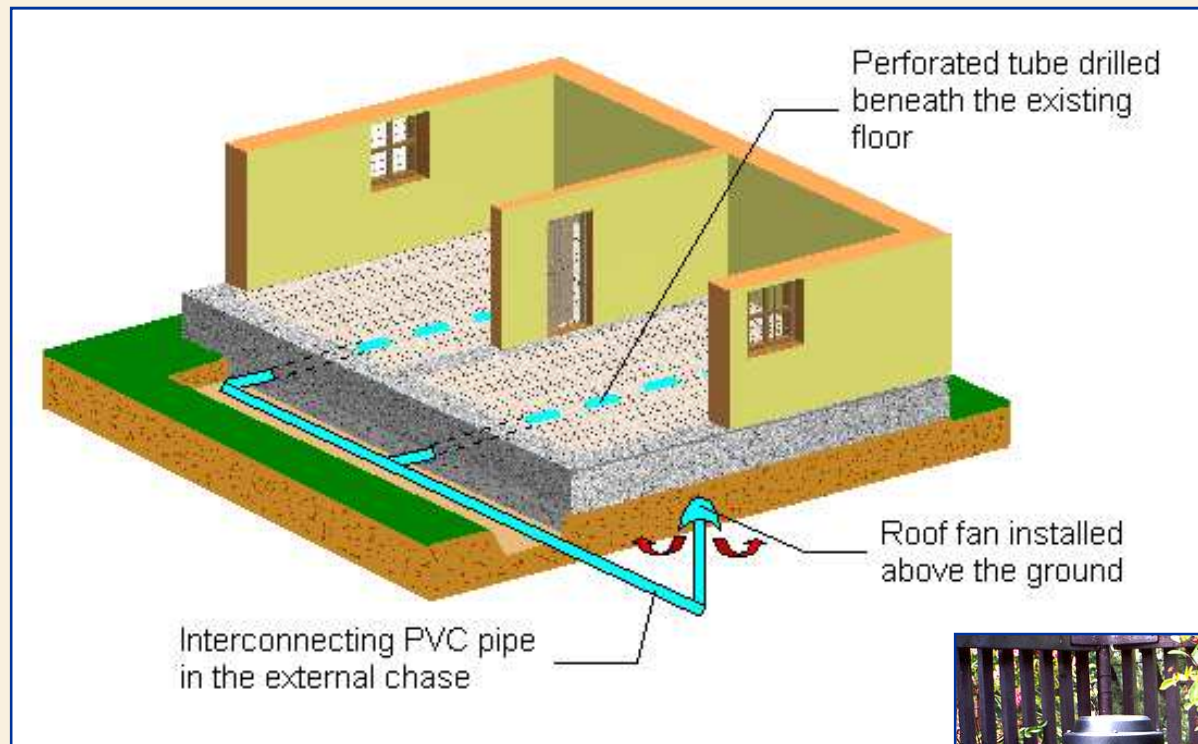


# Radon sump





# Perforated drilled tubes

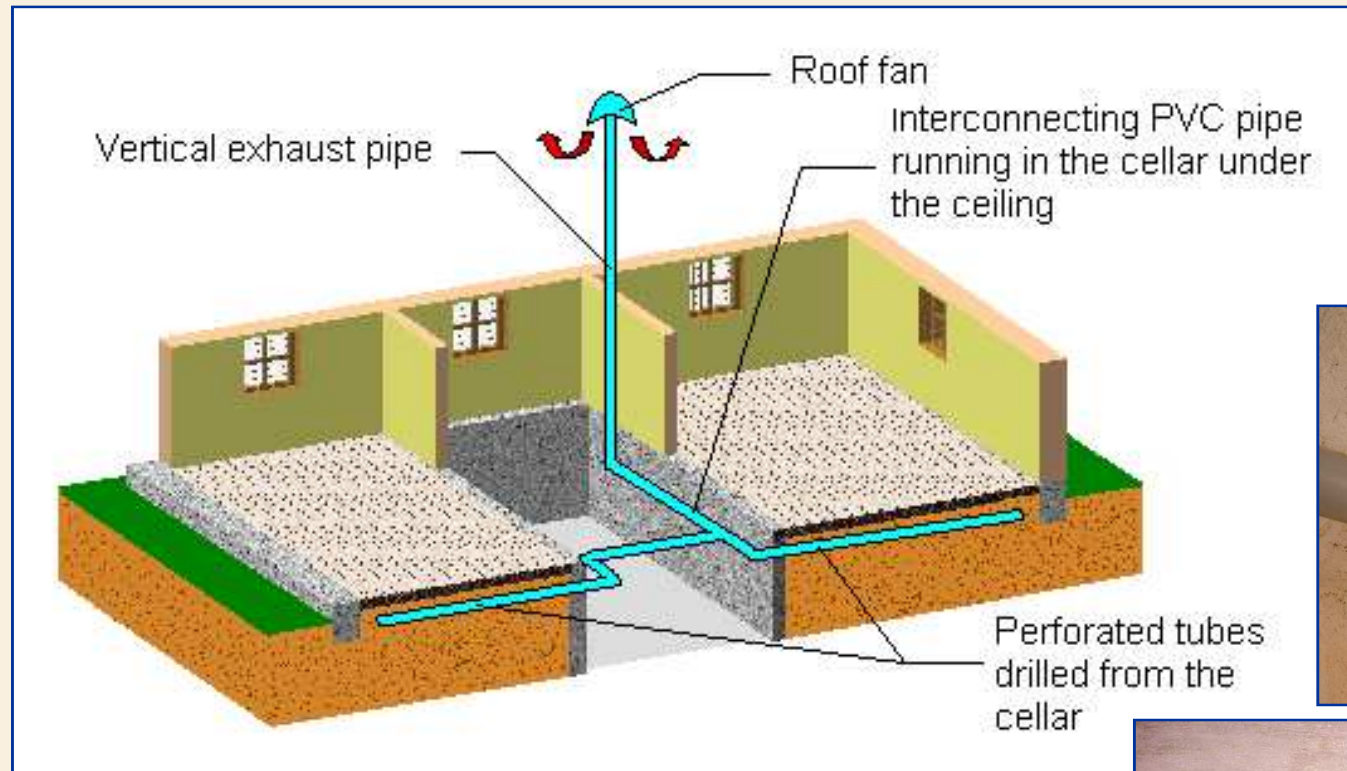


**Tubes drilled from  
the external trench**





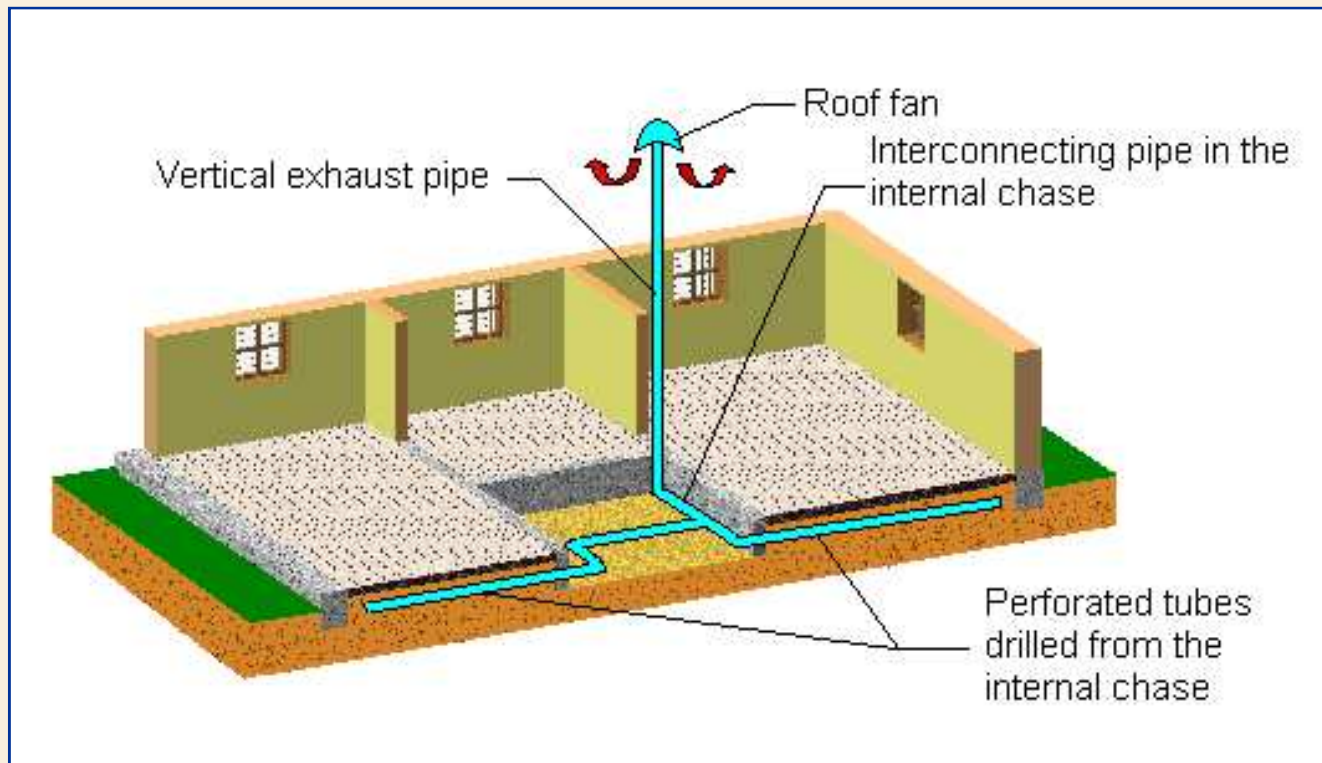
# Perforated drilled tubes



**Tubes drilled from the cellar**



# Perforated drilled tubes



**Tubes drilled from the internal pit**

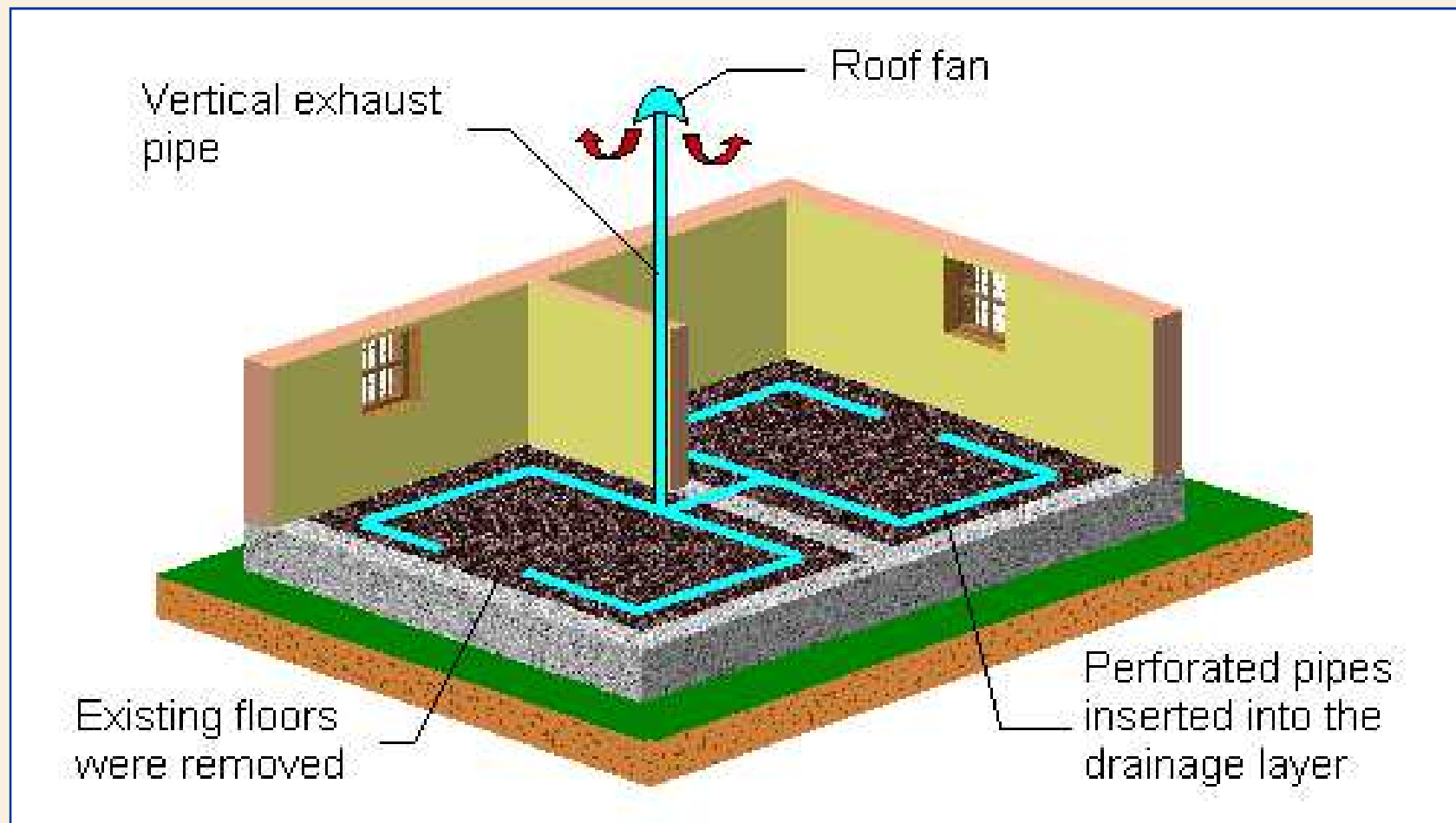




## Example - realization



# Network of flexible perforated pipes

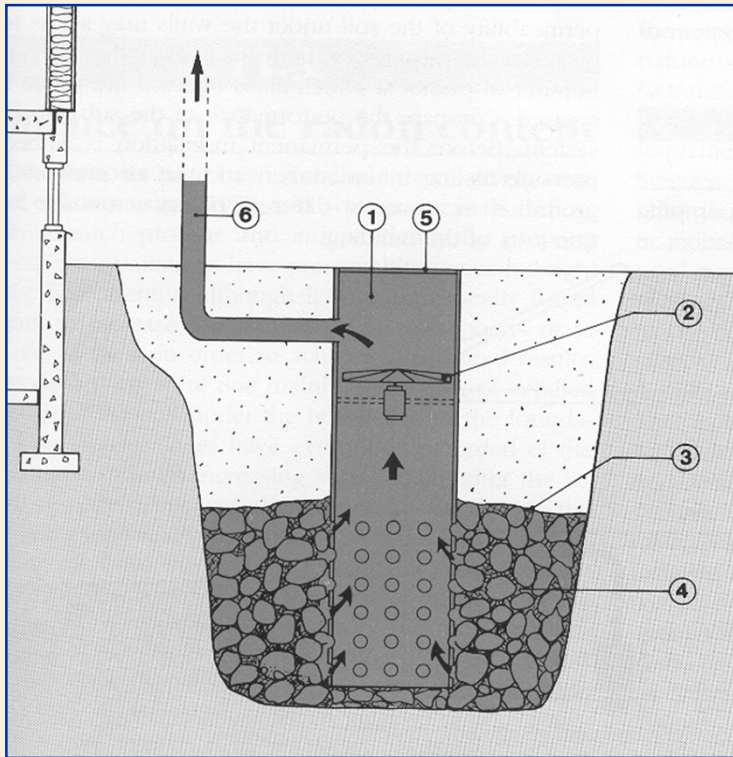




## Example - realization



## Special case: „Radon well“



***Arrangement of a Swedish radon well:***

***1 - 0,4 – 1,0 m diameter pipe with holes at the bottom end***

***2 – fan***

***3 – sealing plastic foil***

***4 – suction chamber***

***5 – cover***

***6 – vent pipe***

Intended mainly for use in sick layers of  
**highly permeable soils (gravel, coarse sand).**

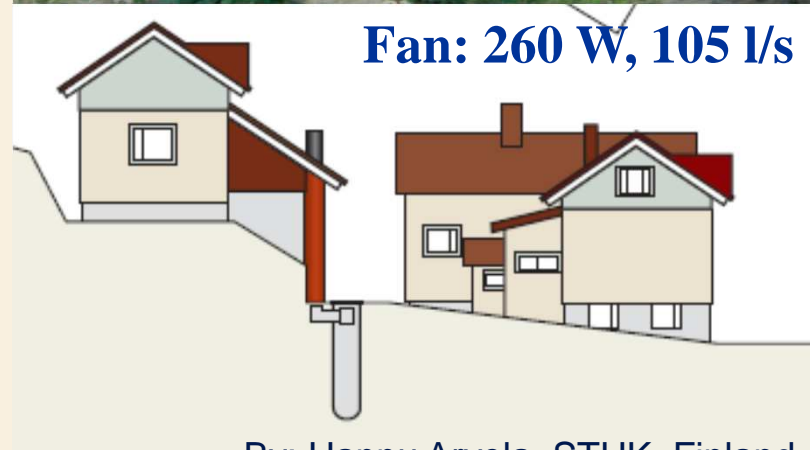


# Radon well

## Examples from Finland



Fan: 250 W, 60 l/s

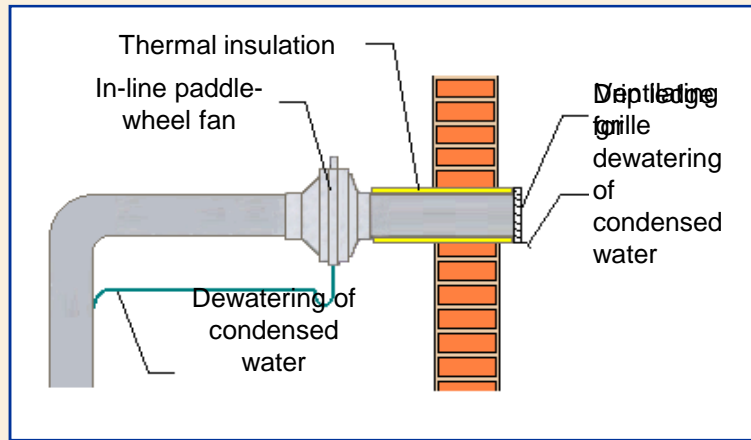


Fan: 260 W, 105 l/s

By: Hannu Arvela, STUK, Finland

# Fans suitable for SSD systems

## Typical paddle-wheel fan installations



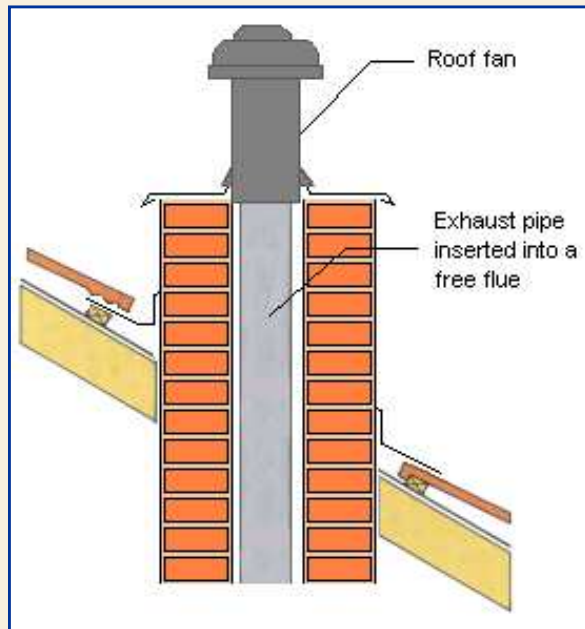
## Fans in plumbing and inspection chambers





# Fans suitable for SSD systems

## Typical roof fan installations



# Fans suitable for SSD systems

## Typical roof fan installations



# Fans suitable for SSD systems

- Fan sizing depends on the airtightness of floors, vertical profile of soil permeability and the geometry and length of ventilation pipes
- Fans must be able to transport soil air with a relative humidity from 80 % to 100 % and to resist the flow of condensed water
- Fans should not be installed in the habitable zone
- SSD should not induce underpressure indoors in order not to influence the operation of combustion appliances

# 3. PRINCIPLES OF CORRECTIVE ACTIONS

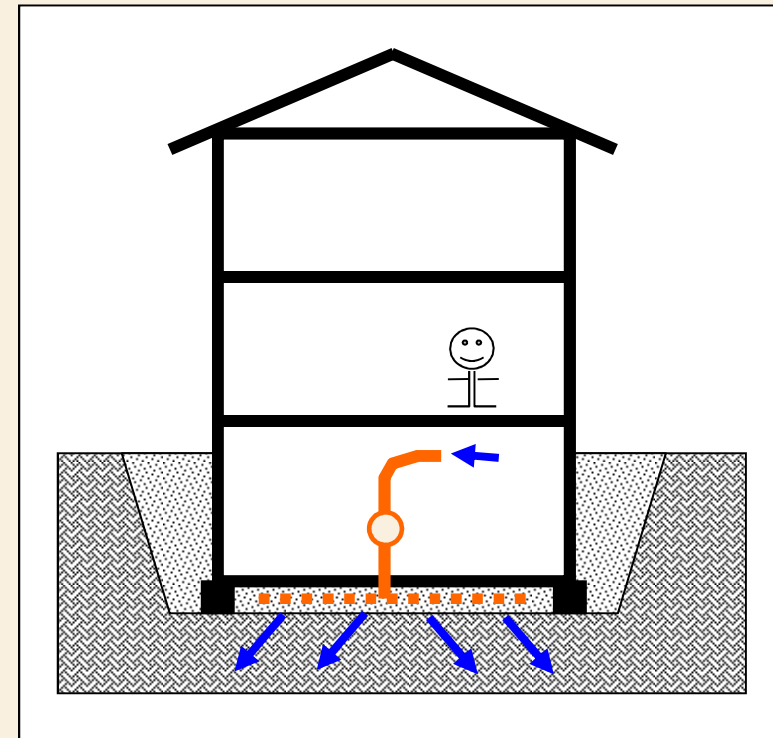
## 3.4 Creating overpressure in the subsoil

Known also as **air cushion** method.

The principle is that indoor air is forced in the sub-floor region, in order to dilute radon concentration under the building.

Used rarely, when sub-slab depressurization is not effective.

Effectiveness can be as high as  
85 - 95 %.



From UK and USA experience this works best in  
highly permeable soils.



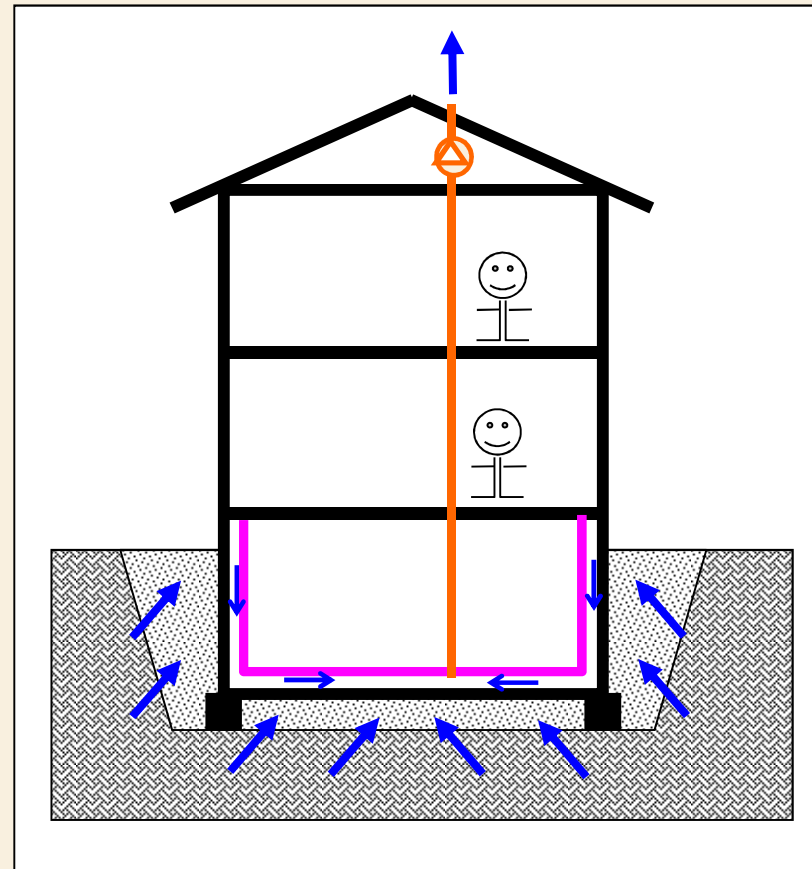
# 3. PRINCIPLES OF CORRECTIVE ACTIONS

## 3.5 Creating underpressure in the air gaps formed over the contact structures

The gap can be formed also along walls made of uranium rich materials. In this case the method serves for removing radon exhaled from the wall.

Effectiveness is around 90 %.

Suitable also for radon from building materials!



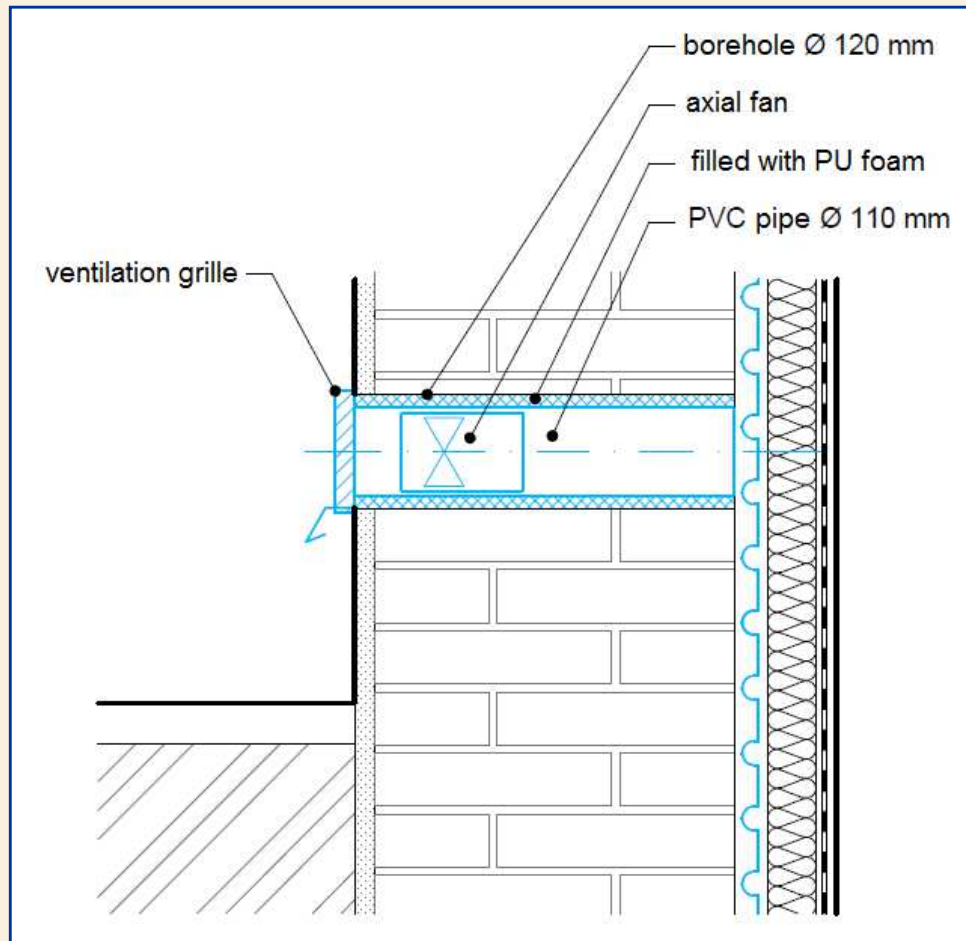
# AIR GAPS DEPRESSURIZATION

- Condensation of water vapour in the gap should be prevented.
- Active ventilation creating a slight underpressure within the gap is preferred. Active ventilation is executed without any vent holes delivering external air into the gap.
- Soil air must not be used to ventilate the air gap. When ventilating with internal air, the back flow of air from the gap to the interior must be prevented (e.g. using back-flow valves located in the vent holes).

# AIR GAPS DEPRESSURIZATION

## Location of fans

In case of greater pressure losses, the axial fan should be replaced by paddle-wheel fan installed on the external surface of the wall

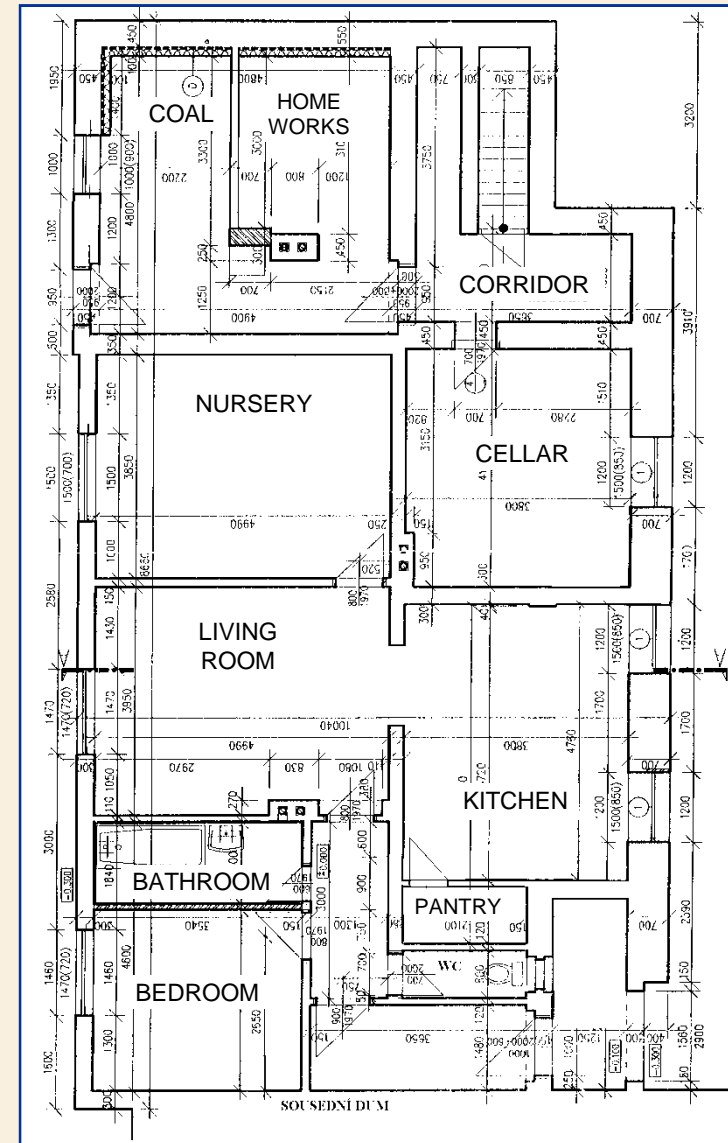


# Example of wrong application of the floor air gap

## Existing single family house



Indoor radon concentration before mitigation: 600 Bq/m<sup>3</sup>





## Example - original corrective action

1999 - 2000:  
new floors + passive air gap  
ventilation



Indoor radon concentration after  
corrective action  
1 150 – 2 250 Bq/m<sup>3</sup>

### Reasons for failure:

- Natural ventilation through vent holes of insufficient dimension located in perimeter walls only (without vertical exhaust) – underpressure was not generated in the gap
- Leaky connection of the dimpled membrane to existing walls
- Leaky joints between dimpled membranes
- Underpressure generated in the house sucked radon from the gap to indoor space

# 3. PRINCIPLES OF CORRECTIVE ACTIONS

## 3.6 Increasing ventilation rate of the habitable space

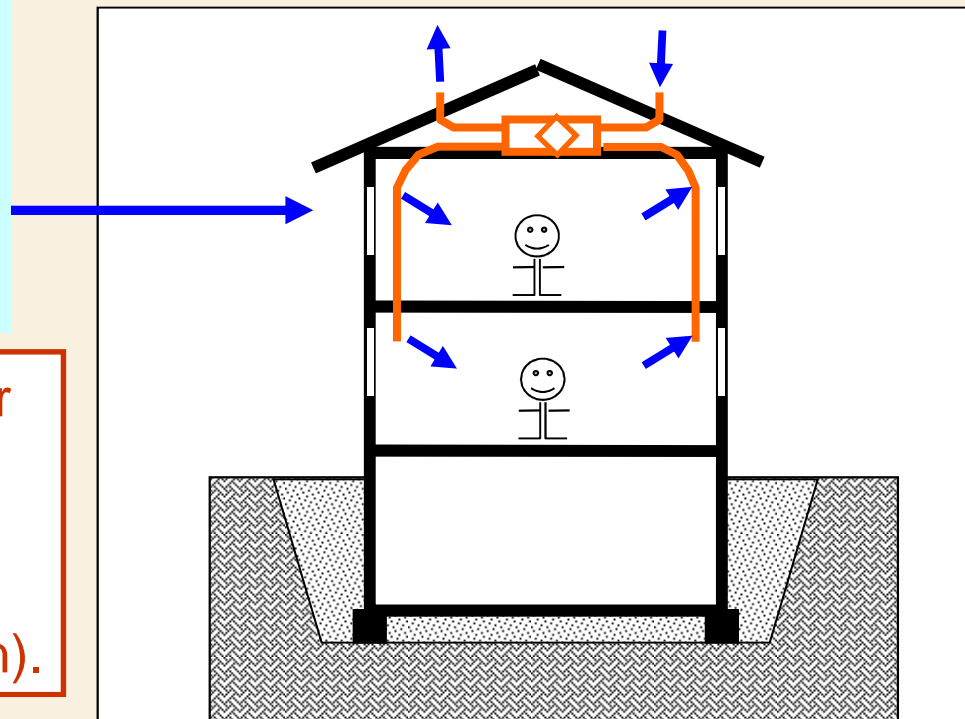
Can be ensured by:

- improving natural ventilation
- installation of hybrid or mechanical ventilation

Effectiveness is usually lower than

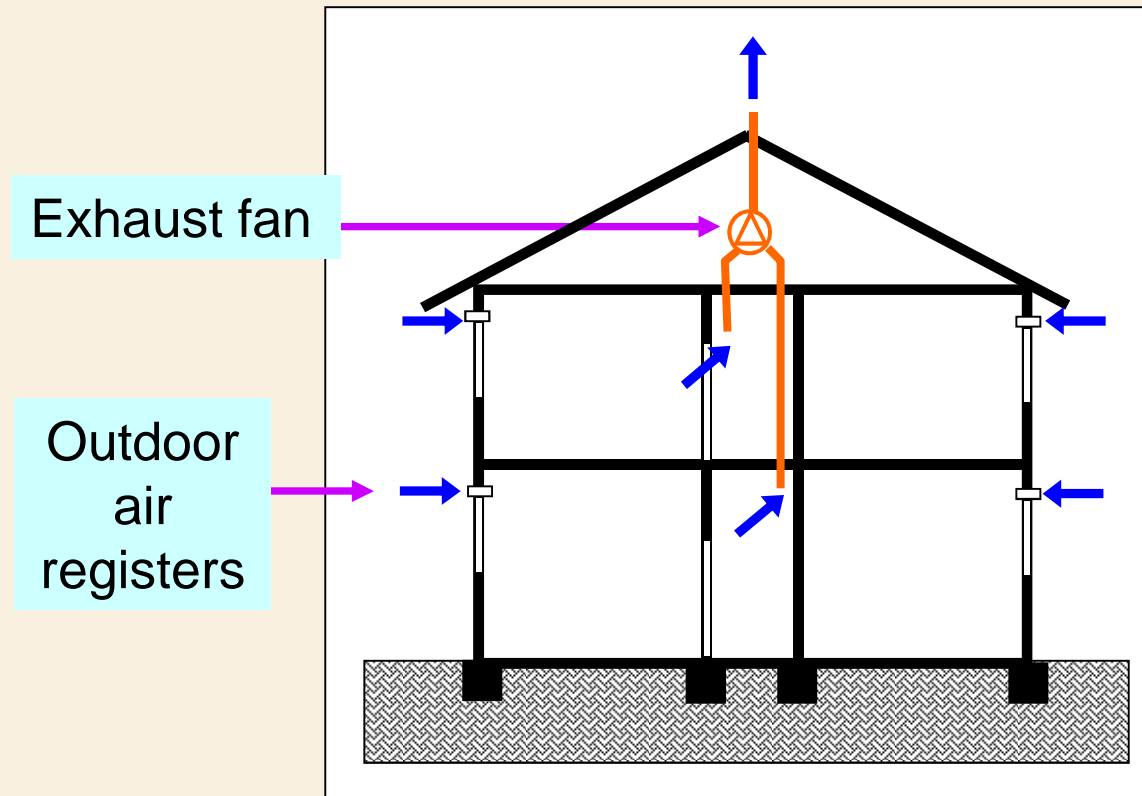
< 40% (natural ventilation)

< 70% (mechanical ventilation).



Suitable not only for radon from the soil, but also for radon from building materials!

### 3.6 Increasing air exchange rate by installing mechanical exhaust air ventilation



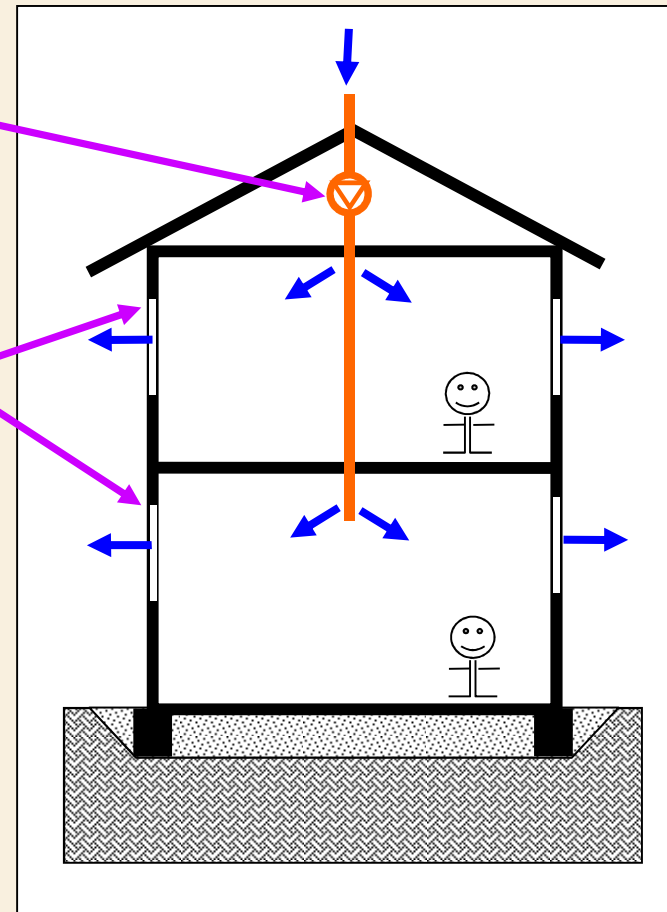
### 3.6 Mechanical supply air ventilation (positive ventilation, house pressurization)

Supply fan +  
filter + heater

Indoor air escapes through  
leakages around window  
frames and between window  
frames and casements

Not suitable for attached houses

Increased risk of water  
vapour condensation within  
the building envelope  
construction.

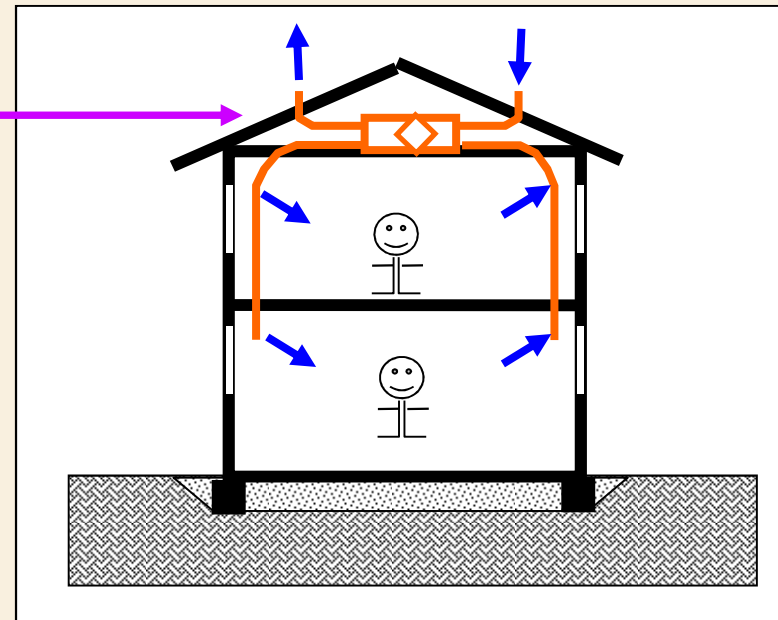


### 3.6 Mechanical supply and exhaust air ventilation for the whole house

Ventilation unit with filters, heat exchanger, heater and fans.

Due to energy costs the ventilation rate should not exceed  $1,0 \text{ h}^{-1}$ ,

otherwise supplementary measures (sealing of the substructure) should be adopted.

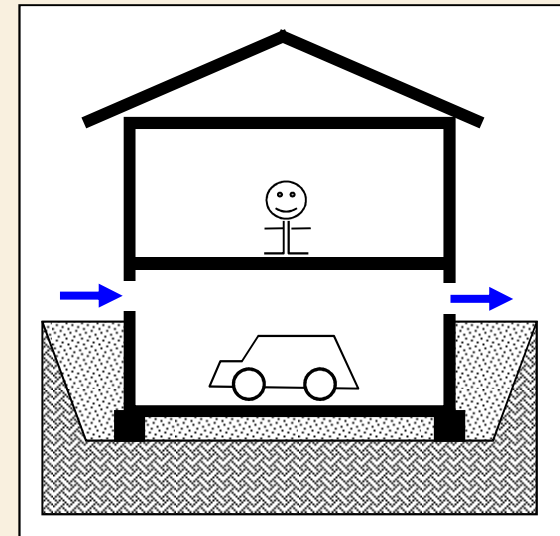
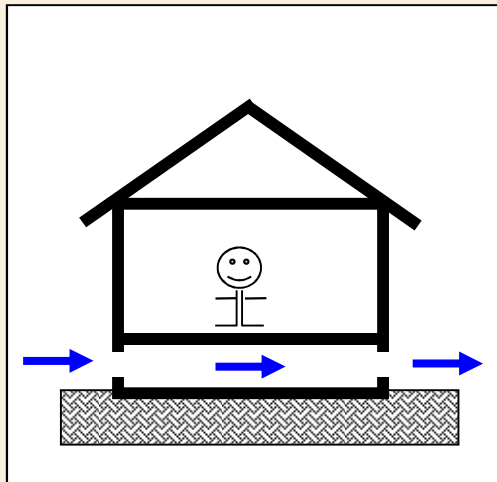


All rooms with radon concentration above  $300 \text{ Bq/m}^3$  should be ventilated.

### 3.7 Increasing ventilation rate of crawl spaces or non-habitable spaces

Can be ensured by:

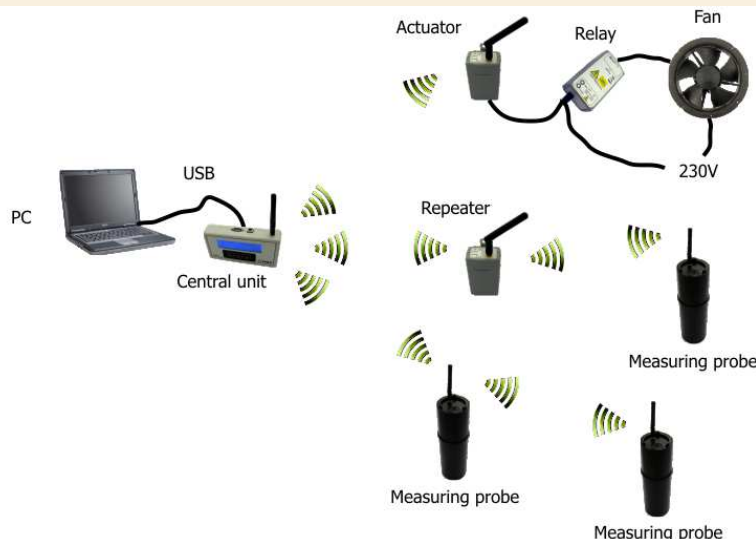
- improving natural ventilation
- installation of mechanical ventilation



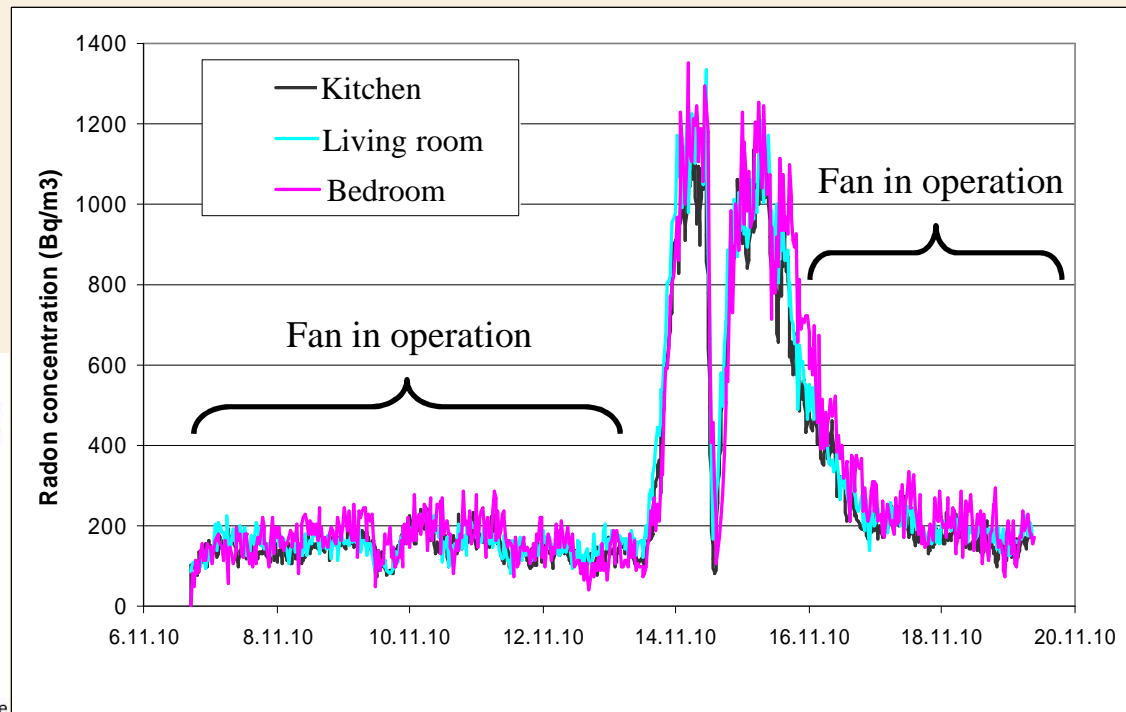
Effectiveness is usually around 50% (natural ventilation) or 75% (mechanical ventilation).

# How it works - example : Radon concentration after the active corrective action was applied

**NEW:**  
Rn detector for  
switching fan



During active ventilation radon concentration decreased to the mean value 152 Bq/m<sup>3</sup>.



# SUMMARY: Effectiveness of corrective actions

*Effectiveness expresses by how many percent radon concentration decreases after installation of a particular measure or combination of measures*

Corrective action	Effectiveness (%)	
	Typical range	Max
New floors with radon-proof insulation	35 - 45	50
New floors with radon-proof insulation + passive sub-slab or floor air gap ventilation	45 - 55	60
<b>New floors with radon-proof insulation + active sub-slab or floor air gap depressurization</b>	80 - 90	<b>95</b>
<b>Active sub-slab depressurization installed without the floor reconstruction</b>	80 - 95	<b>99</b>
Sealing of radon entry points (cracks, pipe penetrations, etc.)	10 - 40	60
Increased <u>natural</u> ventilation of the habitable space	20 - 40	50
Improving ventilation rate by <u>mechanical</u> ventilation	50 - 70	75



## 4. RULES FOR SELECTING ACTIONS

Corrective actions applied in case of „just above“ the reference level ( $C = 300 - 600 \text{ Bq/m}^3$ )

- **sealing of radon entry routes** (cracks, pipe penetrations, etc.)
- **improving the cellar/crawl space – outdoor ventilation**
- **preventing the air movement** from the cellar/crawl space into the first floor
- **improving the indoor – outdoor (natural) ventilation**
- creating a slight **overpressure within the building** (not applicable in countries with cold climates)

## 4. RULES FOR SELECTING ACTIONS

Corrective actions applied in case of  
„well above“ the reference level ( $C > 600 \text{ Bq/m}^3$ )

- The most effective solution is a **sub-slab depressurization** installed without the reconstruction of floors
- Replacement of existing floors by new ones in which the **radon-proof insulation** is combined **with the soil or air gaps ventilation** is selected, when the reconstruction of floors is necessary
- Installation of **mechanical ventilation** is suitable in houses with low ventilation rate (below  $0,3 \text{ h}^{-1}$ ), or where radon problem is caused by radon from building materials

## Some advice:

- Prefer simple actions, inexpensive to install and maintain, it must be easily applicable!
- Apply pragmatic approach and common sense, any initiative of the householder to reduce radon should be supported
- Corrective measures can be installed in stages
- An appropriate solution can be based on combination of different principles (sealing, ventilation, soil depressurization etc.)
- Measure should have sufficient efficiency according to the measured radon concentration (ALARA)
- It should not worsen the technical state and the quality of the building
- It should not disturb the occupants by higher noise levels and other adverse effects
- Operating costs must be at a reasonable level (it should not induce large thermal losses)
- It is advantageous, if other problems and defects of the building are solved together with radon

# Technical standards, workmanship ...

- 1) Prepare technical standards, building codes  
for protection of buildings against radon

Radon corrective actions are part of the building structure. They must be evaluated completely, particularly with regard to building physics, thermal protection of buildings, building waterproofing , ventilation etc.

- 2) Workmanship, skills, experience of the contractor

Prepare national expert(s)– building professional (architect, engineer) for RADON corrective action

## 5. THERMAL RETROFITTING AND RADON

Energy-saving measures increase the air-tightness of the above-ground building shell.

Consequence - > the house ventilation becomes less intense and pressure difference can change. Ventilation rates can decrease up to 4 times!!

### Negative effects:

- impaired quality of the indoor environment
- increased indoor radon concentration

Not only energy needs, but also indoor air quality should be considered when planning energy conversion of buildings

**It is almost always possible to find an optimal solution**

= energy needs are kept to a reasonably low level and the indoor radon concentration is kept to an acceptable level (i.e. below the reference level)

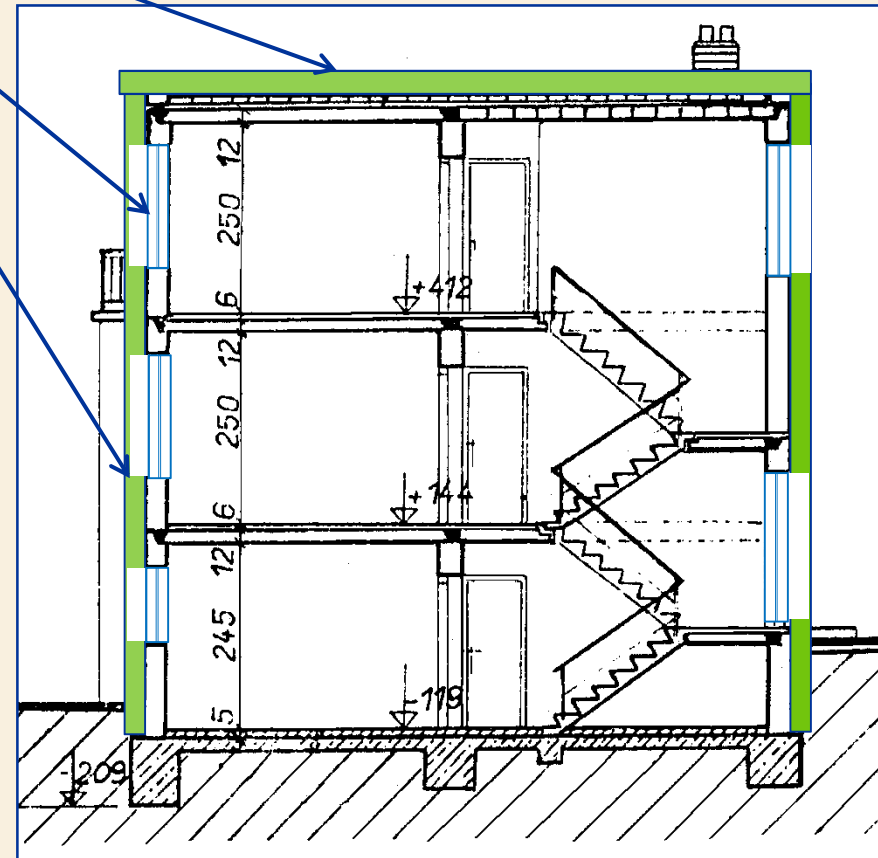
## bad example (CZ) : consequences of thermal retrofitting

## ROOF – 100 mm polystyrene

## New air-tight plastic windows

## ETICS – 100 mm polystyrene

## 2008 – energy-saving measures undertaken





# bad example – consequences of thermal retrofitting

Indoor radon concentration before and after adoption of energy – saving measures (track detectors exposed for 1 year)

Room	Radon concentration [Bq/m <sup>3</sup> ]		Ratio [-] $C_{\text{before}}/C_{\text{after}}$
	before $C_{\text{before}}$	after $C_{\text{after}}$	
Living room + kitchen – 1 <sup>st</sup> floor	302	753	2,5
Children`s bedroom -2 <sup>nd</sup> floor	296	1 165	3,9
Main bedroom - 2 <sup>nd</sup> floor	312	1 524	4,9
Kitchen - 2 <sup>nd</sup> floor	438	1 025	2,3
Mean values	337	1 117	3,4

## Possible reasons

- a decrease in the ventilation rate (higher air-tightness)
- an increase in the radon exhalation rate (ETICS) – not confirmed

Parameter	Before	After	Ratio Bef/Af
Intensity of ventilation n	0,36 h <sup>-1</sup>	0,106 h <sup>-1</sup>	3,4

## 6. RADIUM-RICH BUILDING MATERIALS

### Corrective actions against gamma radiation from building materials

- **Removing building materials** (non-bearing walls, floor fillings, plasters etc.)
- **Application of a shielding** on the surface of radium-rich building materials (it must be verified that the structure is able to carry the additional load from the shielding)
- **Limiting human presence** in the proximity of radium-rich building materials

# Effectiveness of shielding materials

Attenuation – ratio between the gamma dose rate with shielding material to the rate without it

Table from Safety Guide

Shielding material	Thickness of shielding material (mm) for indicated attenuation								
	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Lead 11 300 kg/m <sup>3</sup>	0.9	2.3	4.0	6.3	9.3	13	18	26	38
Iron 7 800 kg/m <sup>3</sup>	6.1	11	17	23	29	37	46	59	81
Barite concrete 3 300 kg/m <sup>3</sup>	12	24	37	50	65	83	100	130	180
Barite concrete 2 800 kg/m <sup>3</sup>	18	34	50	66	84	100	130	160	220
Ordinary concrete 2 300 kg/m <sup>3</sup>	30	50	69	89	110	130	160	200	270
Solid brick 1 800 kg/m <sup>3</sup>	46	72	100	130	160	190	230	280	370

# Testing of shielding effectiveness

## Dry walling – without using a mortar

Brick lining (sand-lime brick, bulk density  $1800 \text{ kg/m}^3$ )

**thickness 65 mm**) – reduction of the gamma dose rate to **66 %** of the initial value.



Brick lining .....

**thickness 140 mm**) – reduction of the gamma dose rate to **54 %** of the initial value.



## Example of removing radium-rich materials



Repeated  
measurement of the  
gamma dose rate in air





# Measures against RADON (from building materials)

## **Suitable measures**

- Removing building materials
- Increasing the ventilation rate
- Creating ventilated air gaps around building constructions

## **Unsuitable measures**

- Impermeable surface coatings (low effectiveness, very sensitive to puncturing and surface condensation)



Thank you

**...and thanks to :**

Martin Jiránek

CZECH TECHNICAL UNIVERSITY

Faculty of Civil Engineering, Praha

E-mail: [jiranek@fsv.cvut.cz](mailto:jiranek@fsv.cvut.cz)

Chris Scivyer, BRE, UK

Bernard Collignan, CSTB, France

Olli Holmgren, STUK, Finland