FINNISH EXPERIENCES IN RADON PREVENTION IN NEW CONSTRUCTION AND ENERGY SAVING CONSTRUCTIONS

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STUK - Radiation and nuclear safety authority

Finland

Radon protection conference
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Outline

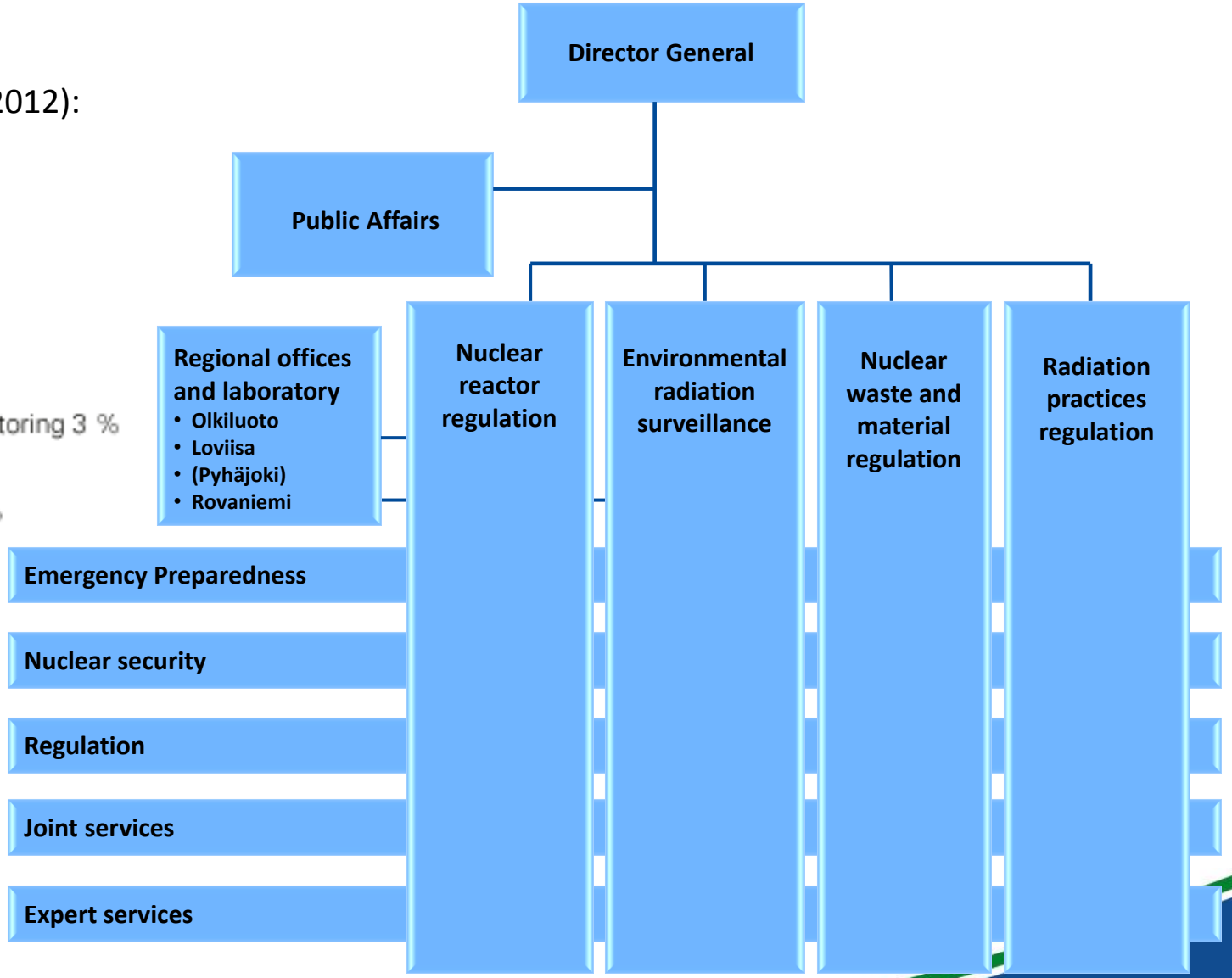
- Introduction
- Radon prevention in Finland
  - Used methods and technical details
  - Effect on radon concentrations
- New construction techniques
  - Air tightness, ventilation strategies and indoor radon
- Summary

STUK organisation

Staff number 358 (2012)

Person-years by sector (2012):

- Nuclear safety 34 %
- Radiation safety 9 %
- Preparedness 3 %
- Research 12 %
- Services 7 %
- Information 2 %
- Environmental radiation monitoring 3 %
- Administration 11 %
- Vacations and absences 19 %



Radon research at STUK in 2013

- Surveys of indoor radon in dwellings, radon mitigation in existing buildings and prevention in new building
- Aim: production of expert information for prevention of high indoor radon concentrations
  - Utilised in the development of guidance and a national radon strategy in cooperation with other authorities
- Radon scientists:
  - Hannu Arvela
  - Heikki Reisbacka
  - Tuomas Valmari
  - Olli Holmgren
- Radon measurement service: 5 persons





Päivi Kurttio
Head of Laboratory
Health Risks and Radon Safety

finland.fi welcome!

People: 5.2 mil

Housing: 1.4 mil dwellings in houses, 1.1 mil apartments

Average radon level: 100 Bq/m^3

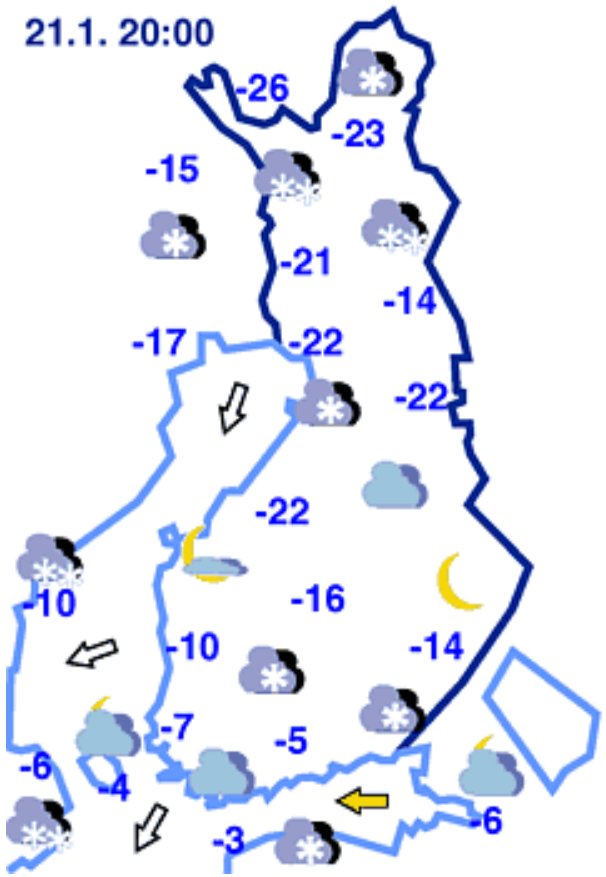
Soil: moraine, gravel, sand, clay

Climate:

Average temperature (1981-2010)	South	North
July	+18 °C	+15 °C
January	-4 °C	-13 °C
Annual	+6 °C	0 °C

Factors increasing indoor radon concentrations

- Cold climate resulting high negative pressure levels
- Permeable soil types
- Average ^{238}U 40 Bq/kg
- Rather tight house envelopes
- Rare airing through windows in heating seasons
- Way of construction of the base floor and foundation

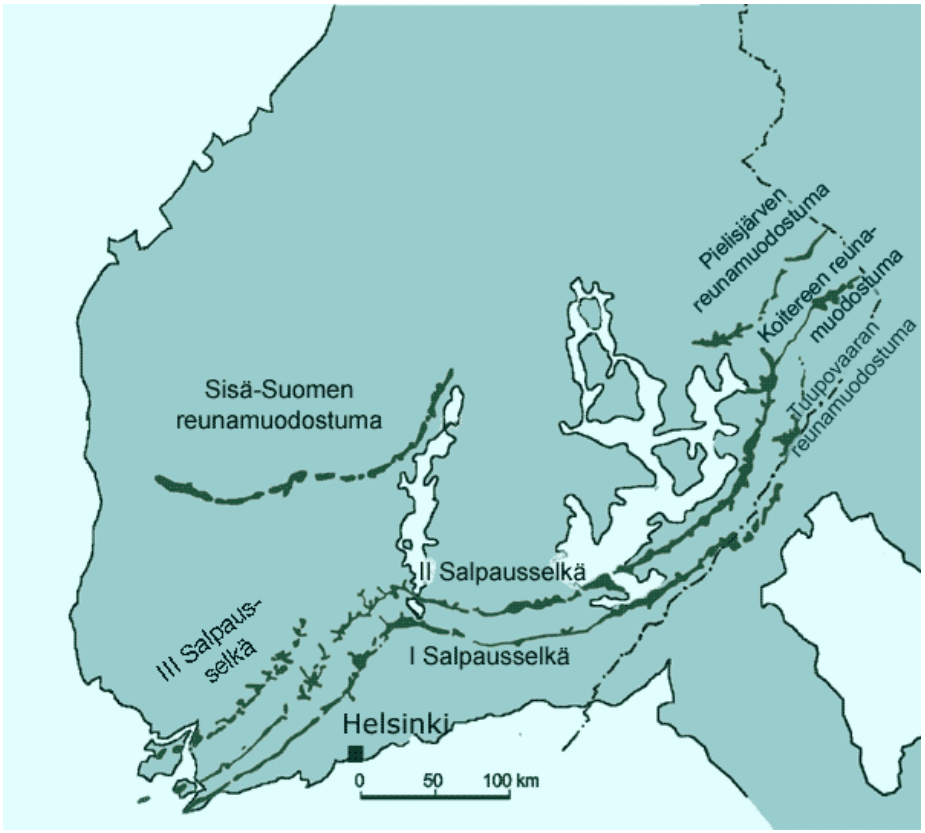


Geography - gravel deposits - eskers

Landscape features were created by meltwater gravel deposit

Pispala esker, Tampere City, Finland

Major esker formations in Finland

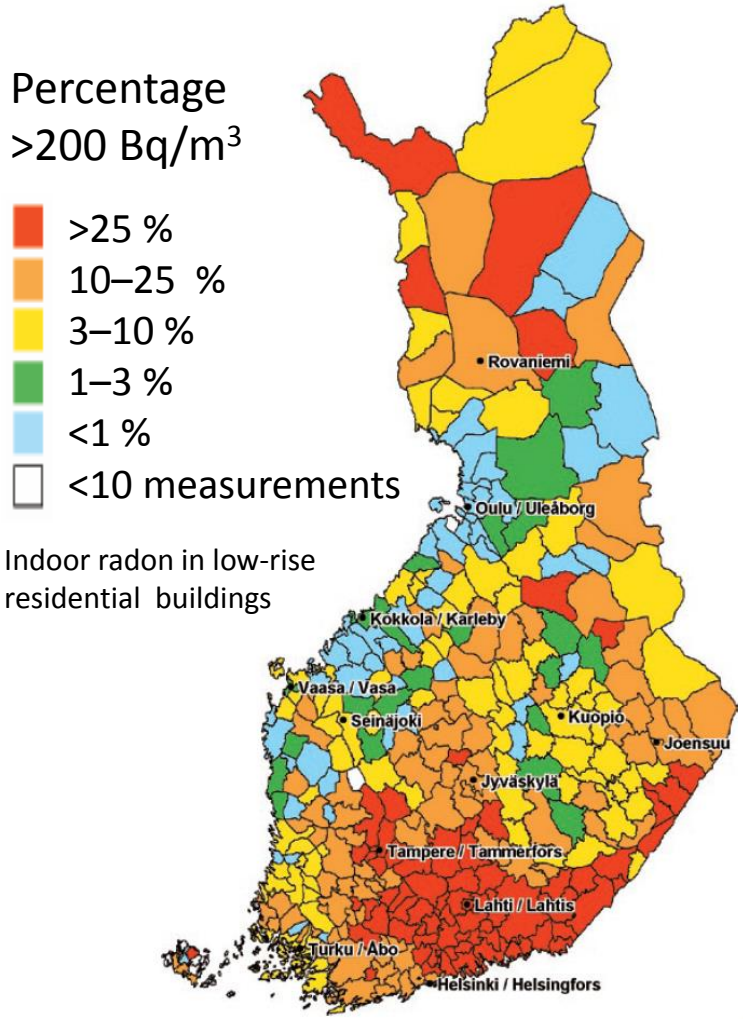


Radon concentrations are high esp. in wide areas in the southern Finland.

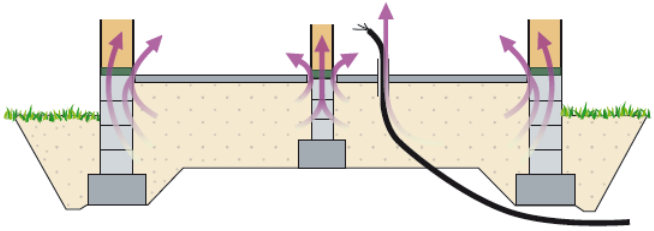
Some eskers are “top radon areas”.

Radon Atlas of Finland 2010

- Based on 87 000 low-rise residential houses measured between 1980 and 7/2008
- Measurement results collected in a national radon data base
  - Almost all measurements in Finland have been done by STUK
- Currently 113 000 houses (8 %) have been measured
  - In radon-prone regions, 10–18% of houses have been measured
- Measurement statistics of all municipalities at www.stuk.fi

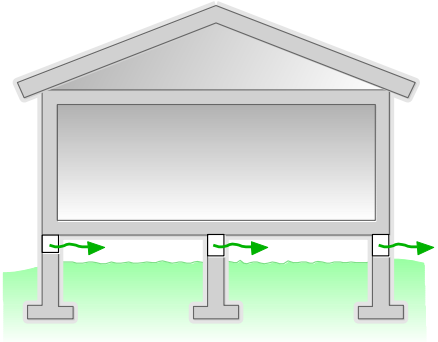


Foundation and base floor types and radon

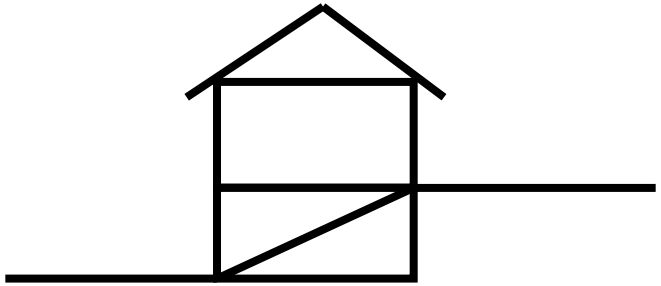


Slab on ground
Prevalence 2006: 64%
High radon levels (mean 96 Bq/m^3)

Monolithic slab
Prevalence 2006: 1%
Low radon levels (mean 38 Bq/m^3)



Crawl-space, suspended floor
Prevalence 2006: 19%
Low radon levels (mean 44 Bq/m^3)

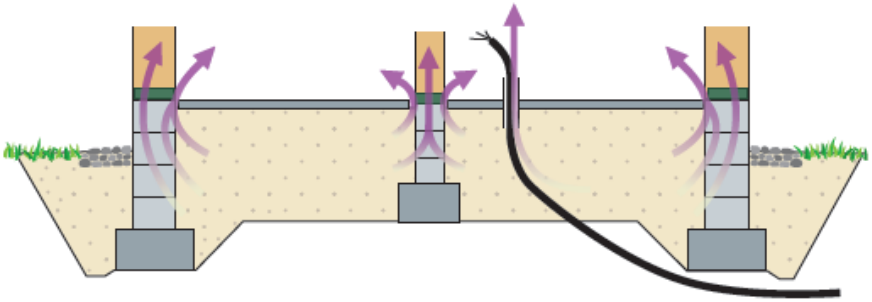


Semi-basement and basement
Prevalence 2006: 16%
High radon (mean 151 Bq/m^3)

Entry routes

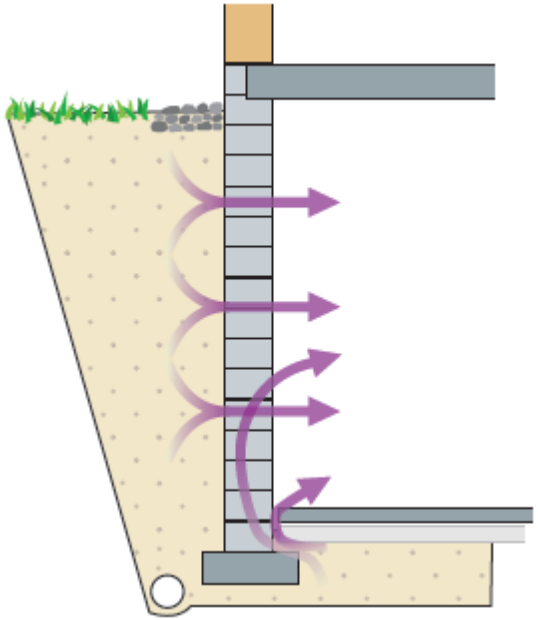
Slab on ground

- Gap between foundation wall and floor slab
- Permeable lightweight aggregate concrete blocks
- Non-sealed pipe penetrations



Basement or semi-basement

- Light-weight concrete blocks and hollow-block walls in contact with soil



Regulations, key changes

New guide for radon prevention in 2003

- Use of a strip of bitumen felt for sealing
- Installation of radon piping (as already in the previous 1993 guide)

New building code for foundations in 2004

- In the design and construction work, radon risks at the construction site shall be taken into account
- Radon-technical design documents are required by the building authorities in municipalities

Guide for radon prevention

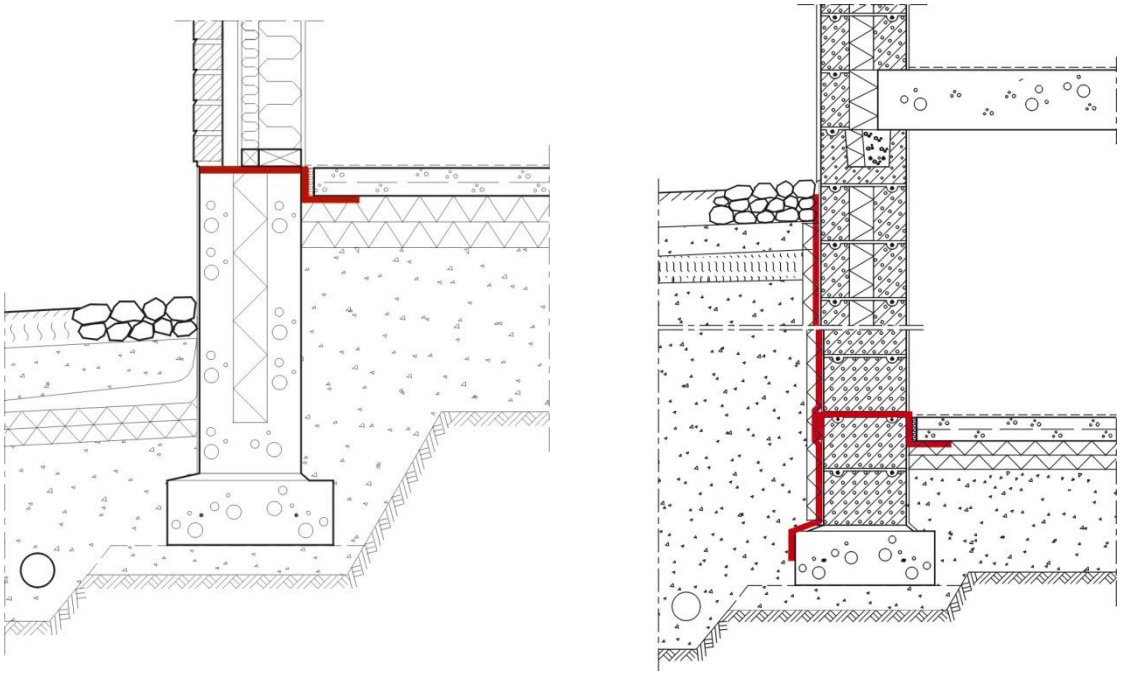
- First guide in 1993
  - Installation of radon piping
  - Sealing with hot bitumen
  - Developed by Helsinki University of Technology
    - Funding: Ministry of environment and Ministry of Social Affairs and Health
- New guide published in 2003
  - Result of a research project,
    cooperation between universities, companies and STUK
  - Use of a strip of bitumen felt for sealing
  - Installation of radon piping
    (as already in the previous 1996 guide)
  - Revised 2012

Radon resistant new construction, guideline

Sealing of joint between slab and foundation wall, and walls in contact with soil

Polyesther-reinforced bitumen felt

• cast in direct contact with bitumen felt at least 15 cm



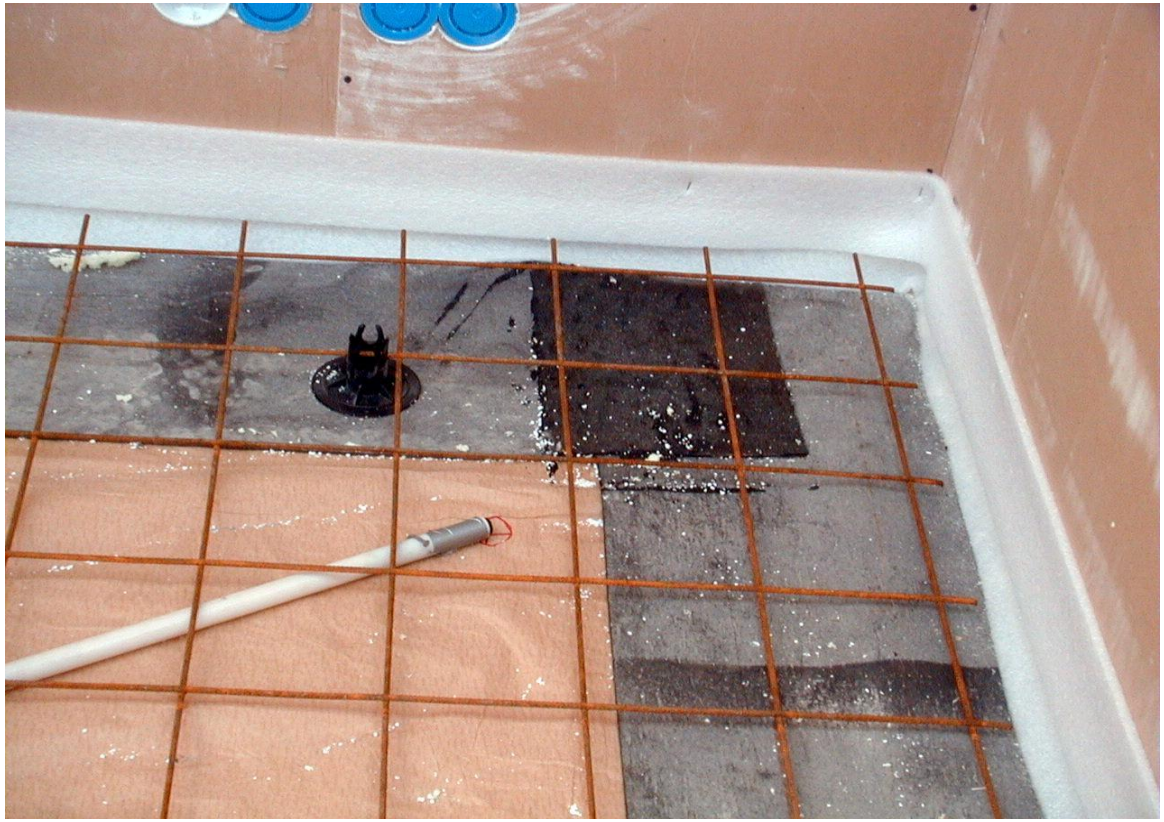
Figures from Guide RT 81-11099

Installation of the bitumen felt

Figures from Guide RT 38056 (Katepal Oy)

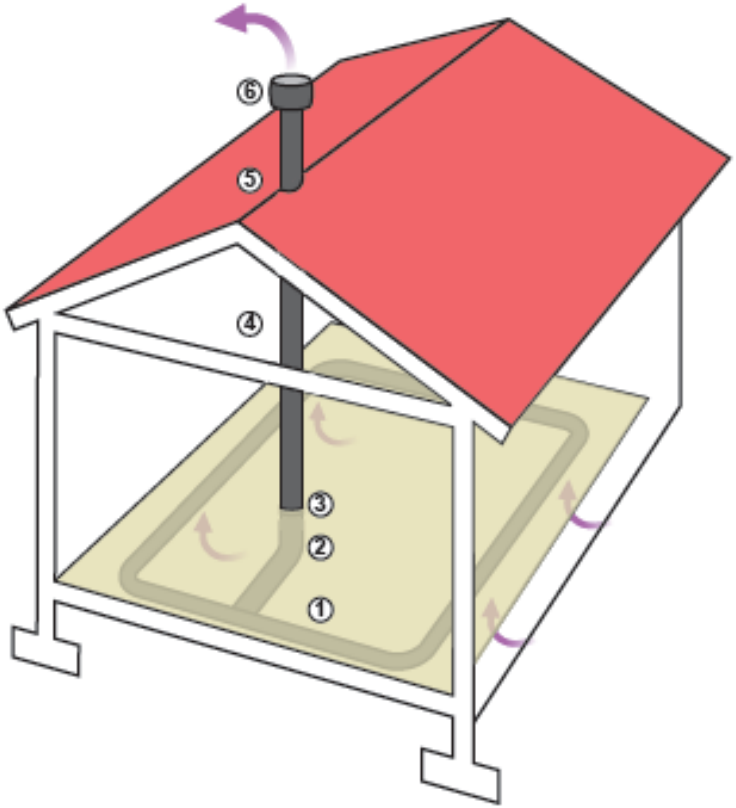
Example of successful sealing work

Bitumen felt before casting of floor slab



Radon resistant new construction, guideline

- Installation of a passive piping system: discharge open above roof



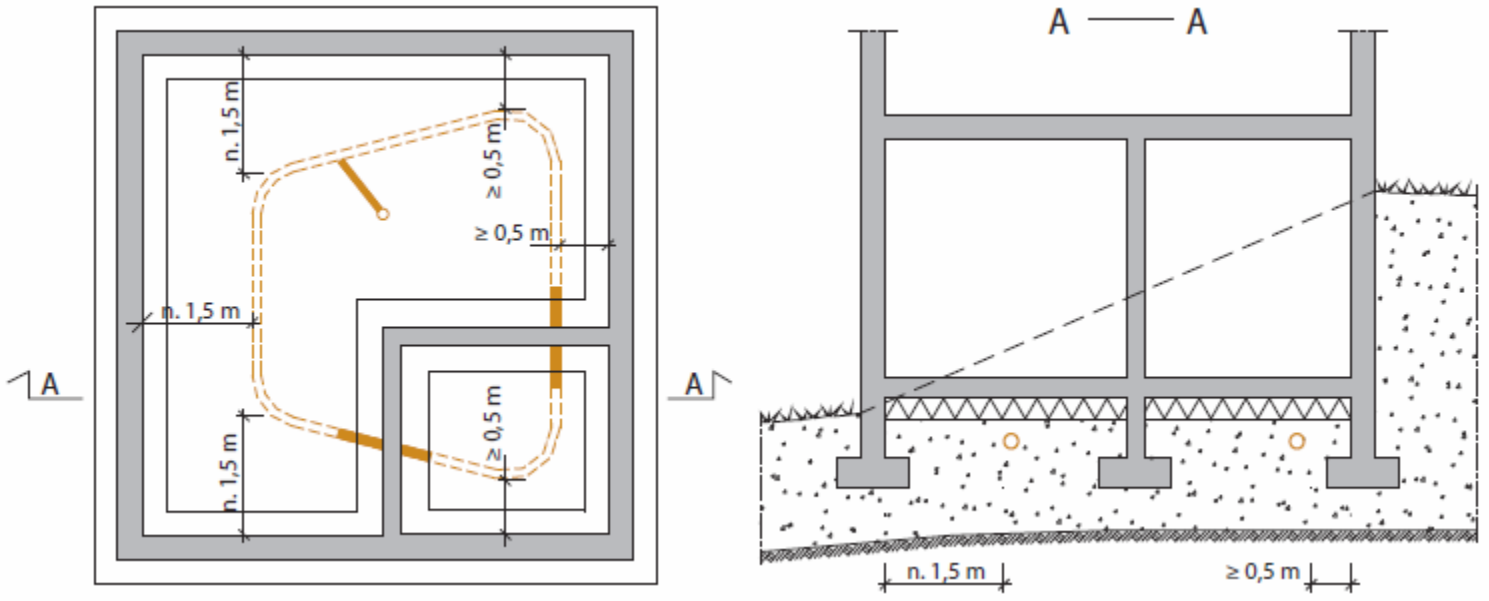
Network of perforated drainage pipe installed below the floor slab

If radon concentration > 200 Bq/m^3, install a radon fan

Installation of radon piping

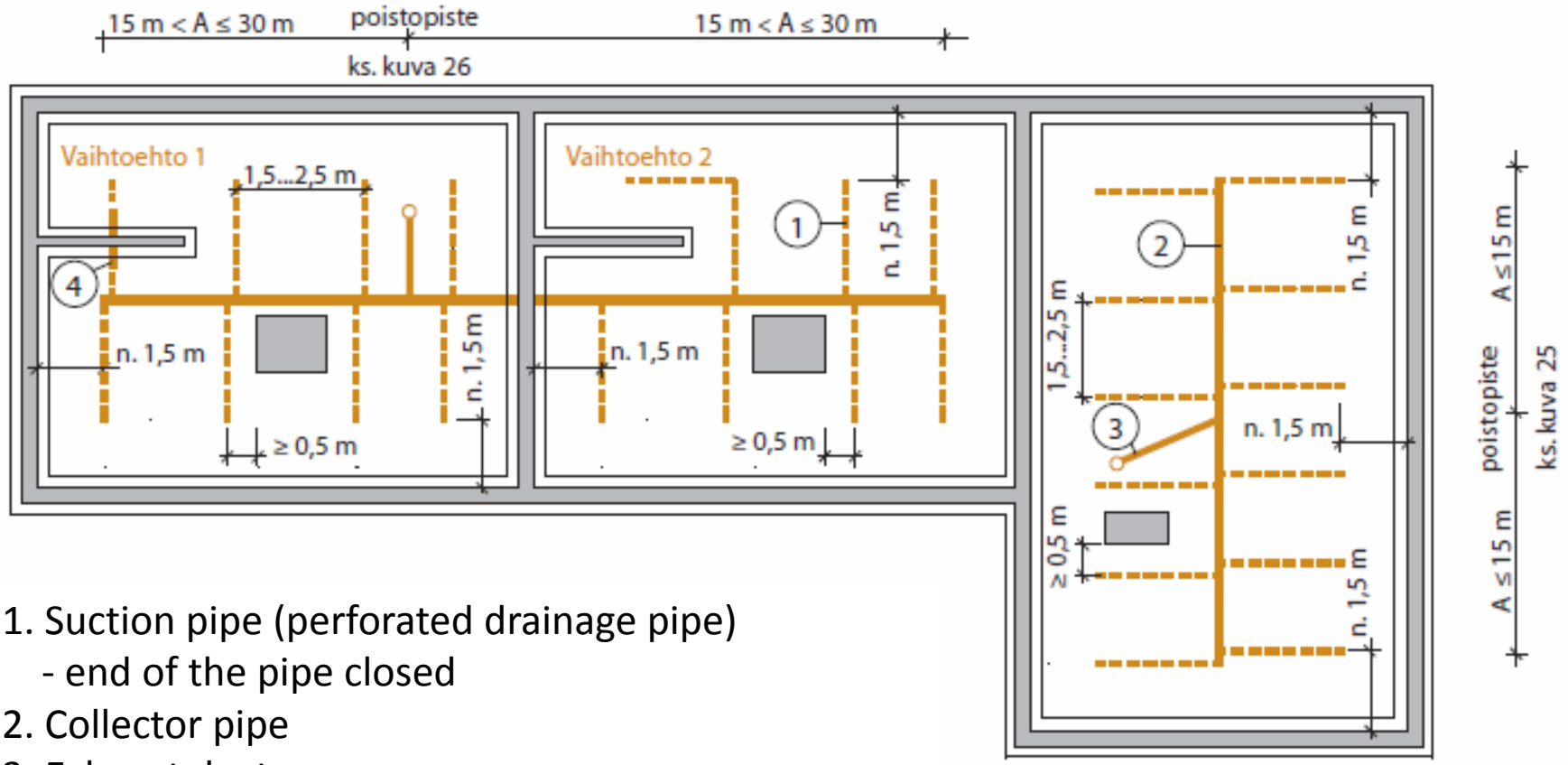
Figure from Guide RT 81-11099

Piping in a house with semi-basement



Figures from Guide RT 81-11099

Multi-branch radon piping



1. Suction pipe (perforated drainage pipe)
   - end of the pipe closed
2. Collector pipe
3. Exhaust duct

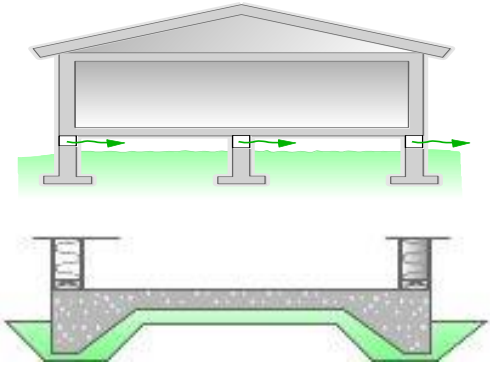
Figures from Guide RT 81-11099

New-construction survey 2009

- Aim: study the effect of new regulations and guidance
- Original sample 3000 dwellings, randomly chosen
  - Building permission given in 2006
  - Notice of removal before November 2008
    (=> Houses completed in 2006 – 2009)
  - 13% of dwellings in low-rise houses that received building permission in 2006 (single family houses, semi-detached houses, terraced houses)
- Radon concentration measured in 1561 dwellings
  - Final participation rate 52 %
  - Two months measurements in March - May 2009
  - Average radon concentration 95 Bq/m^3, median 58 Bq/m^3

Ref. Arvela H, Holmgren O, Reisbacka H. Radon prevention in new construction in Finland: a nationwide sample survey in 2009.
Radiation Protection Dosimetry vol. 148, pp. 465-474, 2012 .

Results, Foundation and radon

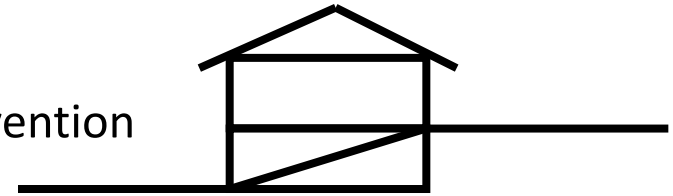


Lowest concentrations

- Houses with crawl space, median 29 Bq/m^3
- Houses with a monolithic floor slab, median 27 Bq/m^3

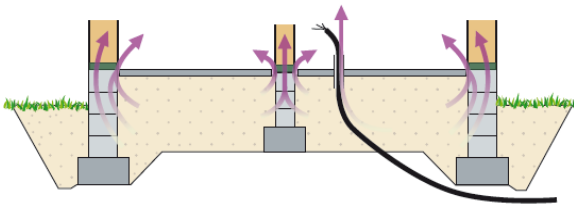
Highest concentrations

- Houses with semi-basement and basement, average 161 Bq/m^3, median 97 Bq/m^3
- Main reason: defective measures for radon prevention in the block walls in contact with soil



Separate foundation wall and slab on ground

- Remarkable progress in radon prevention, average 97 Bq/m^3, median 68 Bq/m^3



Results

- Preventive measures were taken

  - in 92 % of houses in six provinces with highest radon concentration (Area 1)
  - in 38 % of houses elsewhere in the country (Area 2)
  - in 54 % of houses, whole country

Radon concentrations and radon reduction compared with houses completed in 2000-2005 (sample survey 2006)

	New construction survey (2009)	Sample survey (2006)	Radon reduction
Area 1	125 (Bq/m^3)	237 (Bq/m^3)	47%
Area 2	83 (Bq/m^3)	112 (Bq/m^3)	26%
Whole country	95 (Bq/m^3)	142 (Bq/m^3)	33%

Results

- Preventive measures were taken

  - in 92 % of houses in six provinces with highest radon concentration (Area 1)
  - in 38 % of houses elsewhere in the country (Area 2)
  - in 54 % of houses, whole country

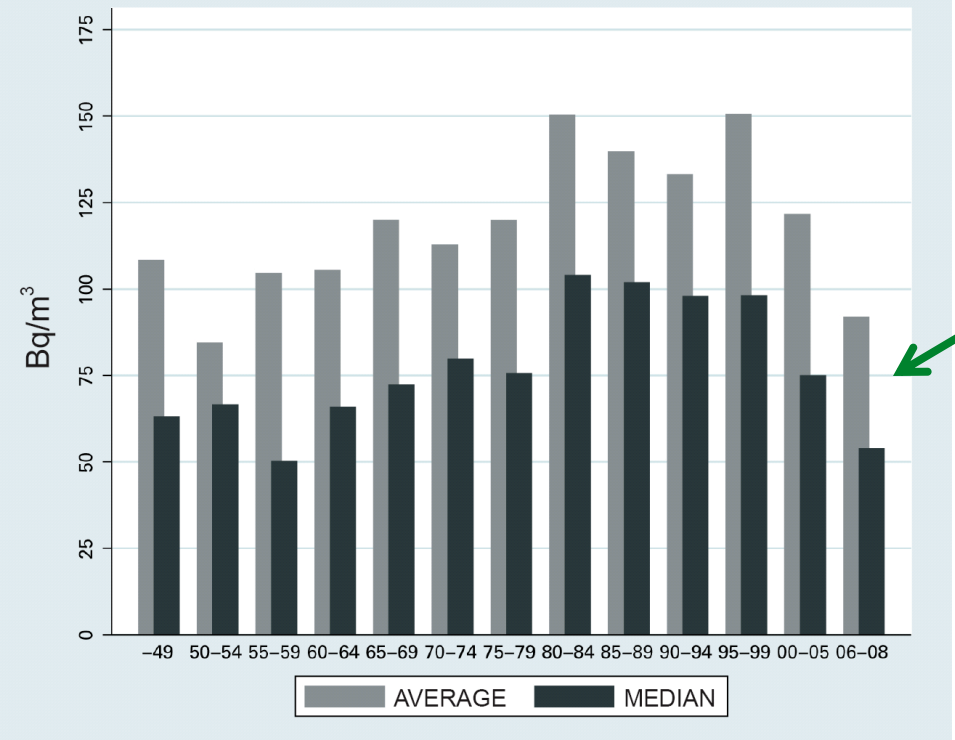
- Percentage exceeding 200 Bq/m3 and 400 Bq/m3

- 200 Bq/m3	10.6%	sample survey (2006)	15.8%
- 400 Bq/m3	2.1%		3.8%

Radon concentration grouped by construction year

Results of 1949 – 2005 are based on the nationwide sample survey 2006 (STUK-A242, Mäkeläinen et al. 2009).

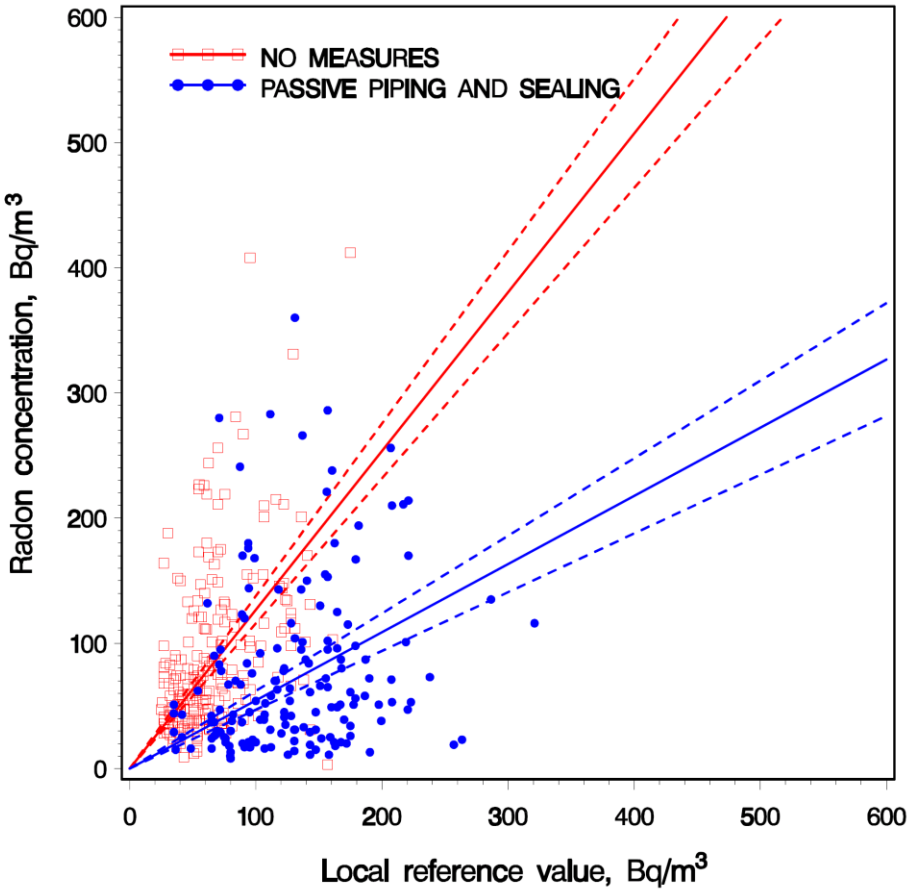
The last bar (2006-2008) represents the results of the new construction study (2009).



Decreasing trend

Effect of preventive measures

Radon concentration in houses with slab-on-ground foundation and local reference values.



Regression lines are fitted for houses

- without preventive measures
- with passive radon piping and sealing carried with a strip of bitumen felt

Local reference data is based on the STUK data base, 87.000 low-rise houses

Effect of preventive measures

- Studied using regression analysis
  - comparison of houses with and without preventive measures

- Radon reduction
  - passive radon piping and sealing with a strip of bitumen felt 57%
  - passive radon piping without sealing 41%

Ref. Arvela H, Holmgren O, Reisbacka H. Radon prevention in new construction in Finland: a nationwide sample survey in 2009.
Radiation Protection Dosimetry vol. 148, pp. 465-474, 2012 .

Challenges

- Widespread and skilled implementation of preventive measures throughout the country
- Lightweight aggregate concrete block walls in contact with soil
- Houses build on crushed rock
- Sealing of pipe penetrations

As a summary, both sealing and passive piping are needed

New construction techniques

- Low energy and passive house construction
  - Increased thermal insulation
  - High air-tightness of the house envelope
  - Mechanical supply and exhaust ventilation with heat recovery

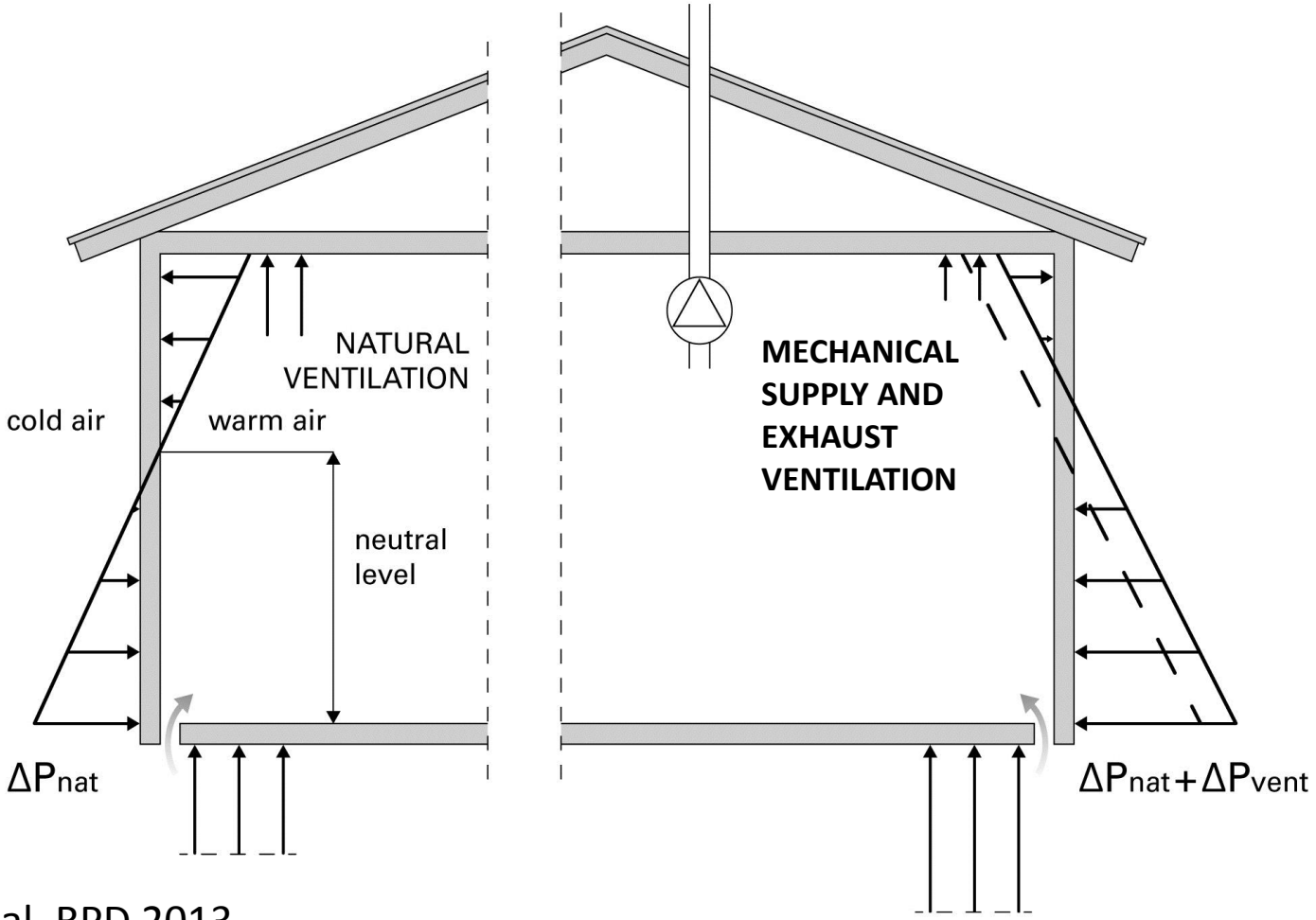
  ⇒ Same goals for passive house construction and radon prevention

  ⇒ In general, these techniques reduce radon level
    - Ref.: RADPAR Deliverable 13/7. Radon and Energy Efficient Construction: Assessment and Recommendations (available online web.jrc.ec.europa.eu/radpar, WP 6)

- Recent Finnish study on air-tightness and indoor radon
  - Ref.: Arvela, H., Holmgren, O., Reisbacka, H. and Vinha, J. Review of low-energy construction, air tightness, ventilation strategies and indoor radon: results from Finnish houses and apartments. Radiation Protection Dosimetry (2013); doi:10.1093/rpd/nct278.

Pressure differences

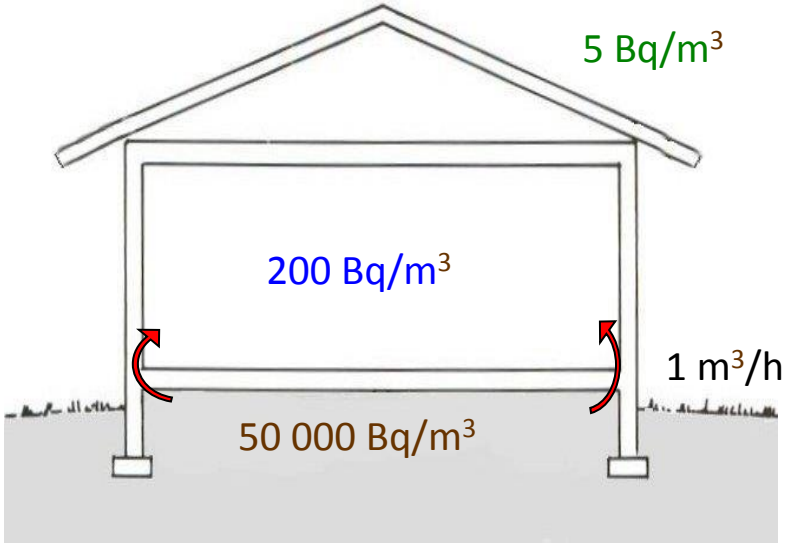
Pressure differences are created by the stack effect and forced exhaust ventilation



Ref. Arvela et al. RPD 2013

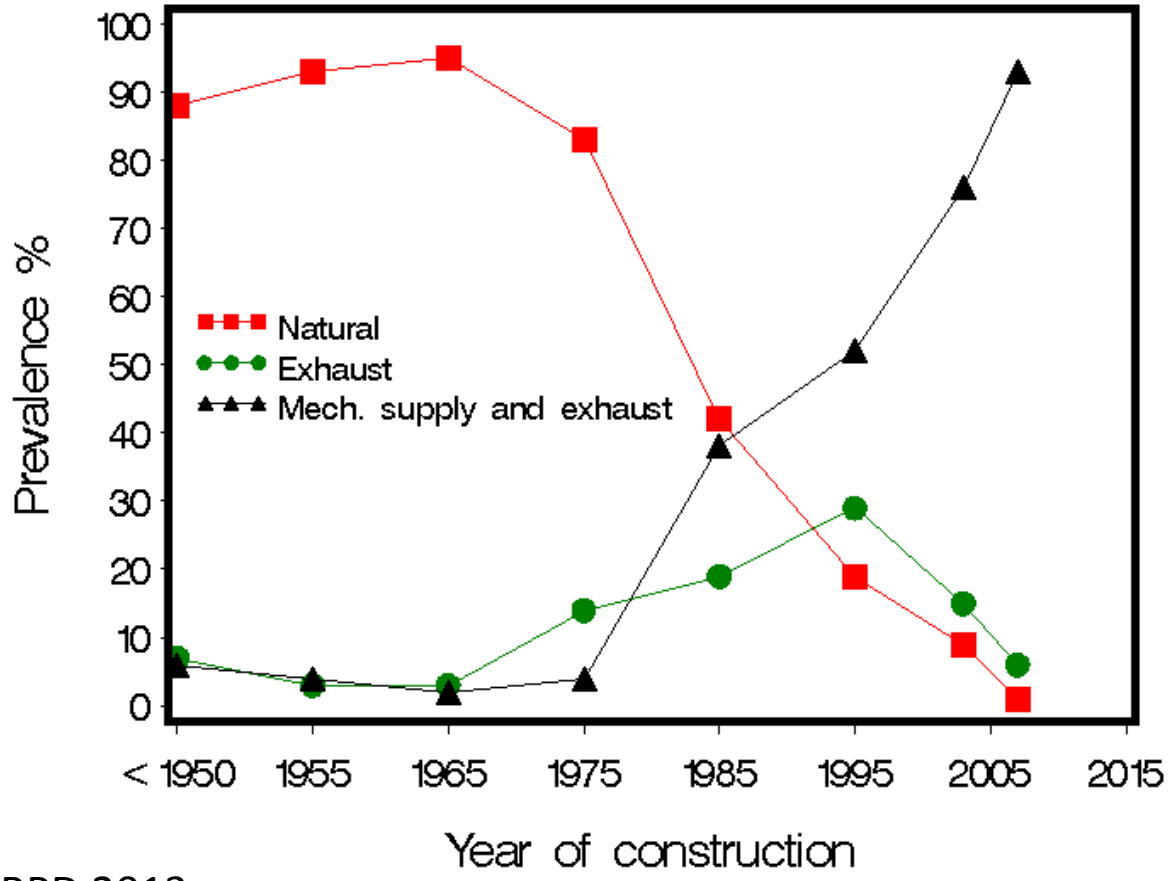
Negative pressure draws soil air into the house

- Even a small gap enables the flow
- Air permeability of the ground affects to the flow
  - On rough soils, higher air flow
  - Rough fillings under the floor slab, promote the leakages
- Even a small air flow can increase the radon concentration above the ref. level



Prevalence of ventilation strategies

Finnish low-rise residential buildings. Source: National random sample surveys.



Ref. Arvela et al. RPD 2013

Ventilation strategy vs. indoor radon

Effect of the ventilation strategy on the indoor radon concentration of detached houses with slab on ground based on measurements in 5312 houses (source: national radon database).

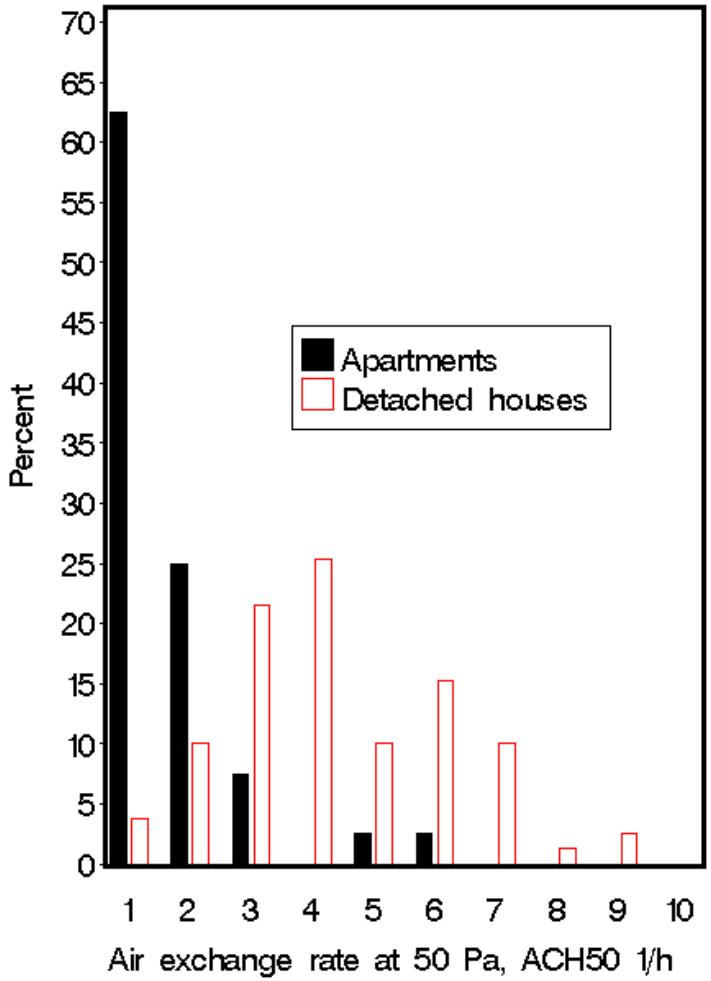
	Natural	Mechanical exhaust	Mechanical supply and exhaust	Total
Number of houses (**1985–1994**)	1538	1438	2336	5312
Radon concentration, average Bq/m^3	348 (1.00)	332 (0.95)	256 (0.74)	303
Radon concentration, median Bq/m^3	**237 (1.00)**	**233 (0.98)**	**178 (0.75)**	**208**
Radon concentration, local reference value, median, Bq/m^3, [1)]	138	153	154	150
Ratio of radon concentration to local reference value, median	1.76 (1.00)	1.64 (0.93)	1.30 (0.74)	1.51
Regression factor [2)]	2.38 +-0.05	2.20 +-0.05	1.70 +- 0.05	2.03
Relative radon concentration compared with natural ventilation, 95% confidence limits [3)]	**1.00**	**0.92 +-0.14**	**0.71 +- 0.14**	

Ref. Arvela et al. RPD 2013

Distribution of the ACH_{50} (n_{50}) leakage factor

Newly built wooden-frame detached houses (1995–2005, n = 79)

Apartments with concrete structures (2001–2003, n = 40)



Ref. Arvela et al. RPD 2013

Air tightness measurements, ACH_{50} (1/h)

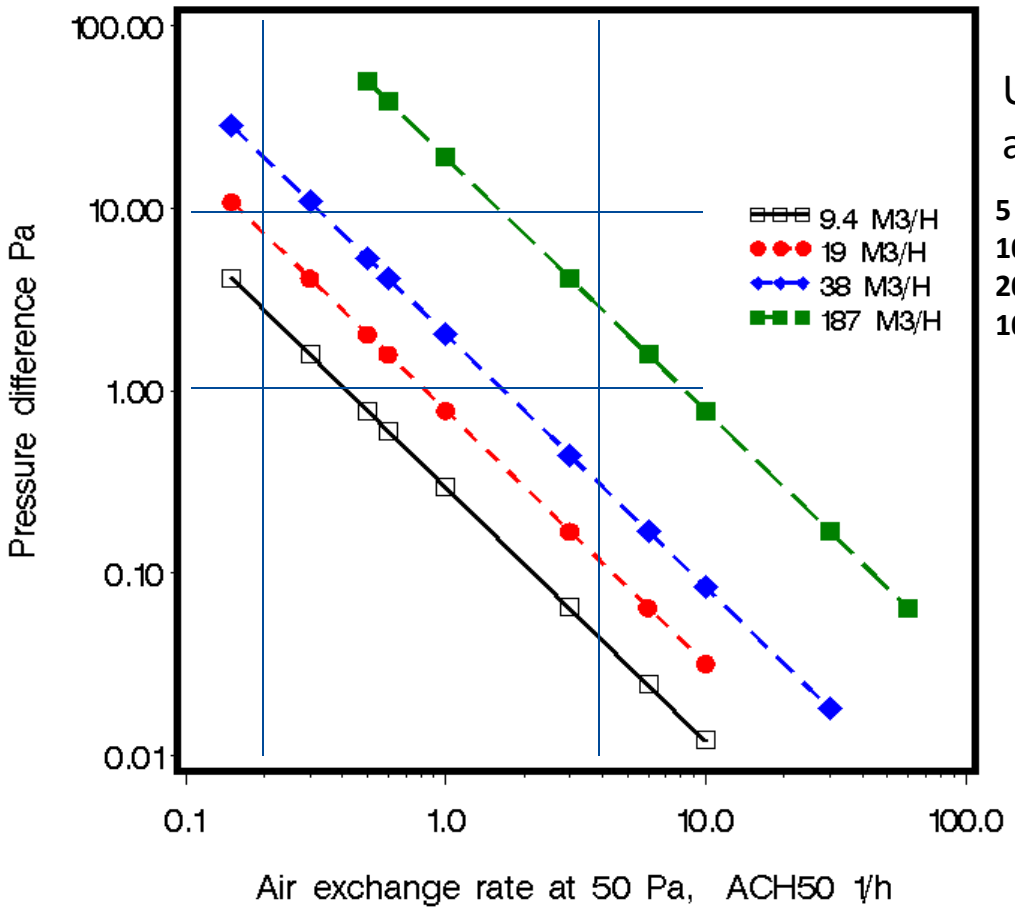
- Finnish detached houses with a wooden frame

Year of construction	N	Mean	Range
1950–1980, Polvinen et al. 1983	61	7.0	2.2–17.8
1978–1982, Polvinen et al. 1983*	28	3.5	1.0–7.5
1979–1982, Metiäinen et al. 1986*	32	2.7	1.1–6.0
1979–1984, Vinha et al. 2005	7	5.2	2.1–7.3
1985–1999, Vinha et al. 2005	40	4.1	0.5–8.9
2000–2003, Vinha et al. 2005	55	3.6	0.6–7.2
2005–2011, Kauppinen et al. 2012	12	1.2	0.9–3.2

* Special emphasis was given to air tightness during construction

Ref. Arvela et al. RPD 2013

Calculated pressure difference vs. air tightness



Unbalance between supply and exhaust air flows

5 % lower supply air flow
10 %
20 %
100 %

Details in Arvela et al. RPD 2013

Ref. Arvela et al. RPD 2013

Summary, Radon prevention

- New regulations in the building code in 2004 has increased considerable the number of houses protected against radon
  - Reference level of 200 Bq/m^3 became mandatory
  - Local building authority requires radon prevention in the building permission, especially in radon-prone areas
  - Detailed guideline for designing radon preventive measures in new construction
- Radon concentrations have reduced 33 % in whole Finland, 47 % in provinces of highest concentration
- STUK recommendations in Finland
  - Radon prevention in all new buildings
  - All remedial actions should aim at radon levels well below the reference level

Summary, New construction techniques

- Low energy and passive house construction
  - Increased thermal insulation
  - High air-tightness of the house envelope
  - Mechanical supply and exhaust ventilation with heat recovery

  ⇒ Same goals for passive house construction and radon prevention

  ⇒ In general, the new techniques reduce radon level

- Recent Finnish study on air-tightness and indoor radon
  - Interaction of mechanical ventilation and high air-tightness increases risk of enhanced negative pressures in dwellings

  ⇒ Challenge to efficient radon prevention (adequate sealing of base floor)

  ⇒ Guidelines for adjusting the ventilation may need revision

References

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- Arvela, H., Holmgren, O., Reisbacka, H. and Vinha, J. (2013) Review of low-energy construction, air tightness, ventilation strategies and indoor radon: results from Finnish houses and apartments. Radiation Protection Dosimetry 2013; doi:10.1093/rpd/nct278.

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Thank you for you attention!

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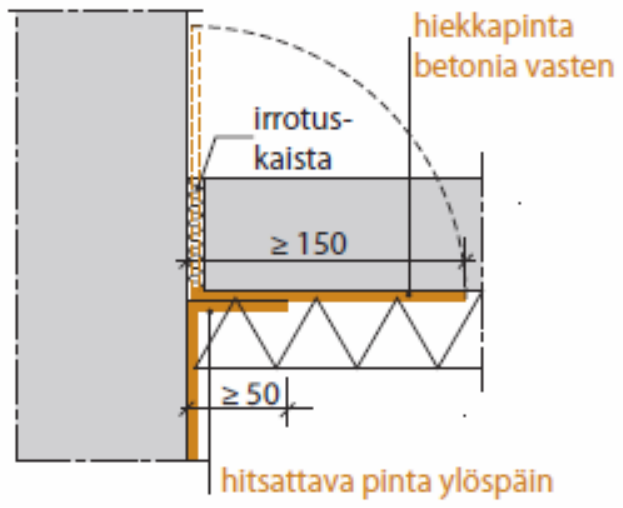
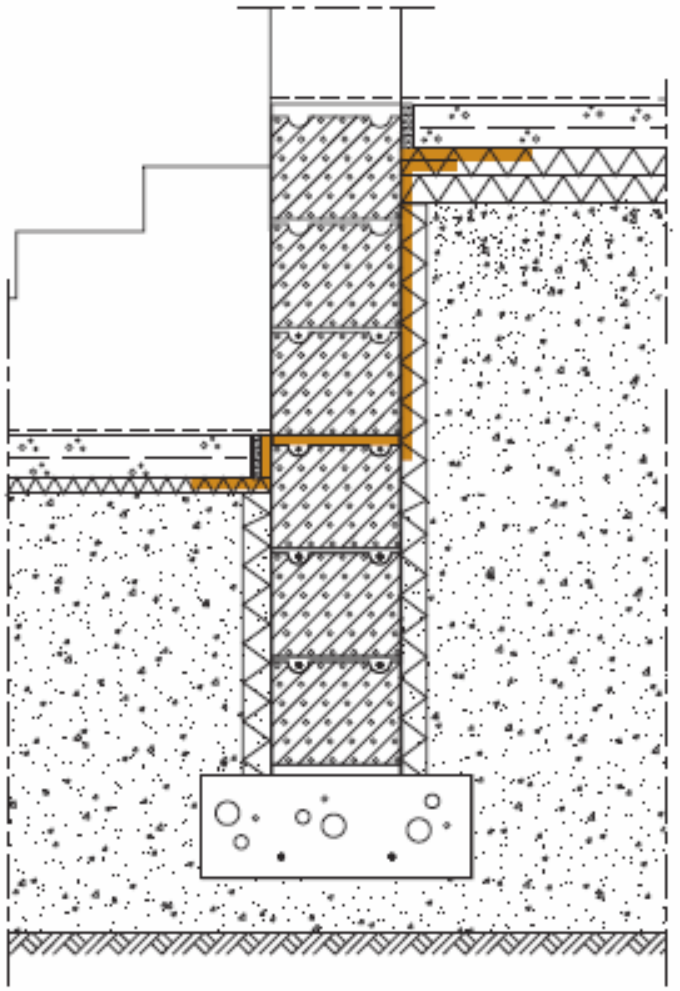
Bitumen felt



Bitumen felt welded to the surface of the foundation wall (concrete)
- two strips needed

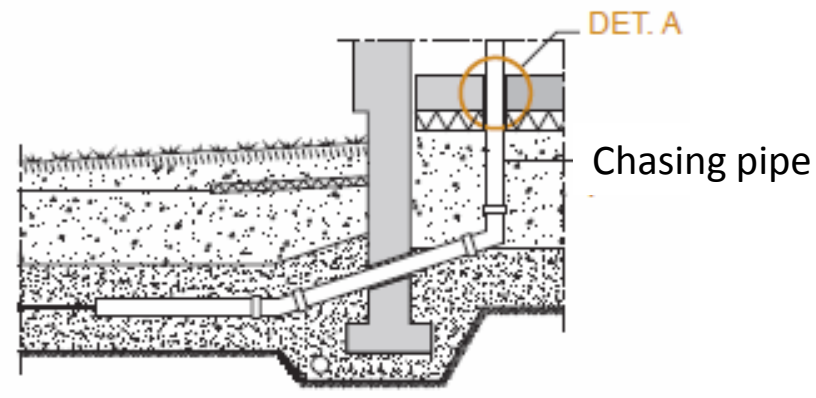
Figures from Guide RT 81-11099

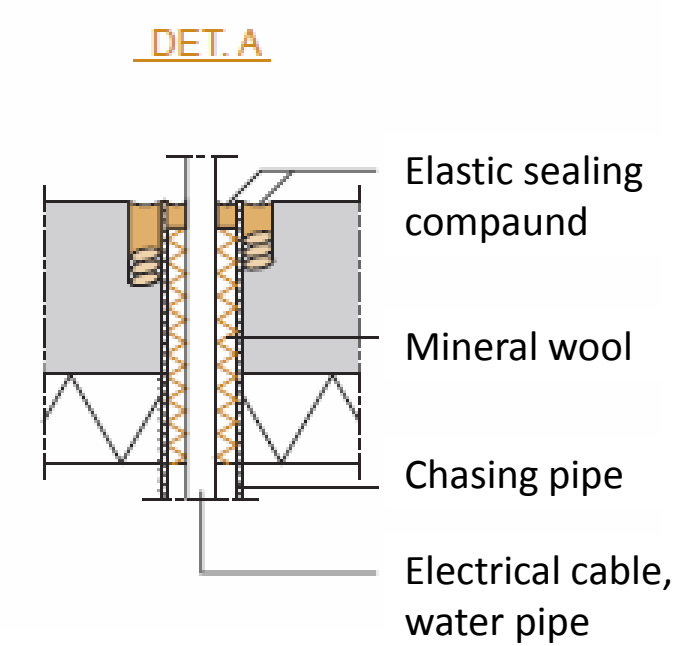


Stepped base floor – three strips of bitumen felt welded together

Sealing of pipe penetrations

- In practice, the sealing is often forgotten, although it would be fairly easy to do.





Figures from Guide RT 81-11099

Dimensioning of the radon piping

Loop-type piping

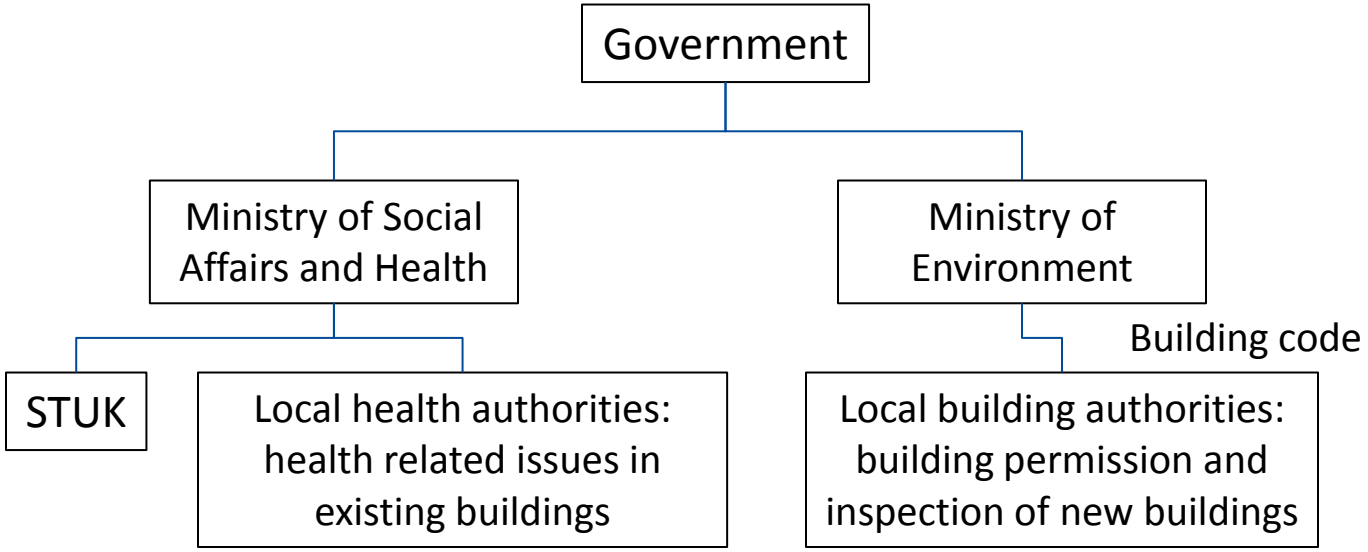
Length of the piping (m)	Diameter of the pipe (mm)
<30	> 80
30 – 45	> 100
45 – 75	> 130

Multi-branch piping

Length of the collector pipe (m)	Diameter of the pipe (mm)
<15	> 100
15 – 30	> 160
Length of the suction pipe (m)	**Diameter of the pipe (mm)**
<10	> 65
10 – 15	> 80

Dimensions are such that standard pipes for drainage systems can be used

Organisations related to indoor radon in dwellings



Non governmental organizations
- Universities: research
- Societies in the area of indoor air: risk communication
- Private companies: remediation and prevention work, measurements

Successful radon policy requires good cooperation between governmental and local authorities as well as expert organizations

Development of energy regulations

- Upper limits for thermal transmittance, U ($W/(m^2 \cdot K)$) presented in the National Building Code of Finland

	1969	1985	2003	2008	2010	Passive house*
External wall	0.41...0.93	0.28	0.25	0.24	0.17	0.1
Base floor	0.35...0.47	0.36	0.25	0.19	0.16	0.08
Roof	0.35...0.47	0.22	0.16	0.15	0.09	0.07
Window	2.44...3.14	2.1	1.4	1.4	1.0	0.67
Door		0.7	1.4	1.4	1.0	

*U-values of a passive house built in Finland fulfilling the international passive house definition