Indoor Rn Concentration and Greek Building Energy Efficiency Regulations. Educating Greek Engineers

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6th EUTERP Workshop, September 30 – October 2, 2015,
Athens Greece

Outline

1. Introduction
2. Greek Building Energy Efficiency Regulations
3. Radon In Indoor Air
4. Educating Greek Engineers
5. Conclusions

Directive 2013/59/EURATOM: provisions for Radon

- The Directive includes provisions for Radon both in the workplace and in homes.
- A national action plan must be established.
- Annex XVIII: List of items to be considered in preparing the national action plan to address long-term risks from radon exposures

  (…)

  (14) Where appropriate, consideration of other related issues and corresponding programmes such as programmes on energy saving and indoor air quality.

Greek Building Energy Efficiency Regulation

- The Greek Building Energy Efficiency Regulation (KENAK) has been put into force according to GGG407/9.4.2010, in compliance with Directives 2002/91/EC and 2010/31/EU.
- An energy efficiency audit is required for:
  - New buildings
    (Total floor area > 50 m^2)
  - Buildings undergoing major renovation
    (Cost of renovation > 25% monetary value of the building)
  - Change of use, or building permit renewal
- An energy class (A-E) is assigned to each building
- Some categories, including industrial use buildings are exempt

Requirements for buildings

- For **new buildings**, a minimum energy requirement is applied: total primary energy consumption (kWh/m^2) should be less than or equal to the reference building (Class B).
- For **major renovation**, the new energy class should be “B” or better if technically feasible. Otherwise, non-feasibility should be explained in detail via technical report.

Class B

0.75 Reference Building < Primary Energy Consumption < 1.0 Reference Building

Effects on air tightness

- Poor building air tightness is a major source of energy inefficiency, due to wasted hear and/or increased cooling needs.
- Achieving the minimum energy requirements as defined by the Greek Energy Efficiency Regulations will create a tendency for increased air tightness.
- This fact raises questions regarding a possible increase in the Radon concentration of indoor air in dwellings and tertiary sector buildings.

Ventilation

- Ventilation is the process whereby indoor air is gradually replaced by outdoor air.
- Ventilation is driven by:
  - pressure differences caused by the wind
  - differences in air density between indoors and outdoors
  - mechanical equipment.
- Characterizing ventilation rates in buildings can be difficult:
  - many buildings are complex structures
  - paths and rates of air movement can depend substantially on location and time.
- In this presentation, estimation of the ventilation rate is approached under the assumptions of the Greek Building Energy Efficiency Regulations.

Types of Ventilation

Natural or mechanical ventilation

This type of ventilation is desired and aims to achieve comfortable and healthy living conditions by the renewal of the indoor air with fresh ambient air.

It is estimated only for the usage time of the building.

Fresh ambient air requirement depends on:

- Building usage
- Number of residents/users

Types of Ventilation

Air Infiltration and exfiltration

This type of ventilation is “undesired” and is caused by the air leakage through cracks and external openings (doors, windows, etc.), air shafts and chimneys.

It is estimated continuously regardless the usage time of the building

Infiltration and exfiltration rates are equal for the small pressure difference of interest, therefore air may be treated as an incompressible fluid

Ventilation types in Energy Efficiency Studies

Infiltration - Exfiltration

- Exists for any kind of building and depends on the level of airtightness of the construction

Natural ventilation

- Achieved through the controlled windows usage. It is applied only for **residential buildings**, unless a mechanical ventilation system exists.

Mechanical ventilation

- It is applied for all **tertiary sector** buildings

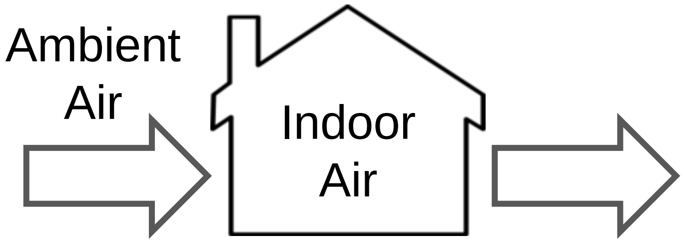
Minimum required ventilation

Ambient air requirements are be defined to meet the minimum required ventilation per hour and per person, depending on the building usage and the person density per square meter of the floor area as well.

Building Usage	Persons/100 m^2	Requirement per Person [m^3/h/Prsn]	Total Requirement [m^3/h/m^2]
House	5	15	0.75
Office	10	30	3.00
Classroom	50	22	11.00
Public Hall	75	30	22.50

Due to comparably low person density, residences meet their needs in ambient air solely through infiltration

Infiltration



- Air filtering around doors, windows and glass areas creates an indoor draught and provides the necessary fresh ambient air.
- Openings such as shafts and chimneys are also a source of infiltration
- When considered thermally, the undesired air infiltration is a loss of energy as it requires redundant heating or cooling.
- Ventilation with natural air currents can entail large heat losses from constant air exchange and inconvenient timing and intensity.
- As buildings become more efficient, infiltration is one of the major paths for heat loss in an otherwise thermally highly insulated building.

Estimation of the infiltration rate

Infiltration through air shaft and/or chimneys depends on the number the type and the dimensions of the current openings

Typical Values for Shafts and Chimneys	
Type of shaft	Infiltration Rate
Fireplace and Heater chimneys	20 m^3/h
Air shafts (i.e. Natural gas boilers)	20 m^3/h

Estimation of the infiltration rate

The air infiltration of the external openings is correlated to the length and to the level of airtightness of the cracks and joints along the openings' frames and it can be estimated from the following formulae.

$$V_v = \sum (l \cdot a) \cdot R \cdot H$$

Where:

$$l\ [m]: Total\ length\ of\ the\ frame\ joints$$

$$a\ \left[\frac{m^3}{h \cdot m}\right]: Airtightness\ coefficient\ of\ the\ frame$$

$$R\ [-]: Air\ infiltration\ coefficient$$

$$H\ [-]: Location\ and\ wind\ coefficient$$

Airtightness coefficient (α)

Frame Material	Type of Opening	α [m³/(h m)]
Wood	Single glaze, non airtight Without glaze, non airtight	3.0
	Double glaze, sliding or opening. Without glaze, non certified airtightness	2.5
	Double glaze, certified airtightness	2.0
Metal or Artificial material	Single glaze, non airtight Without glaze, non airtight	1.5
	Double glaze, sliding or opening. Without glaze non certified airtightness	1.4
	Double glaze, certified airtightness	1.2

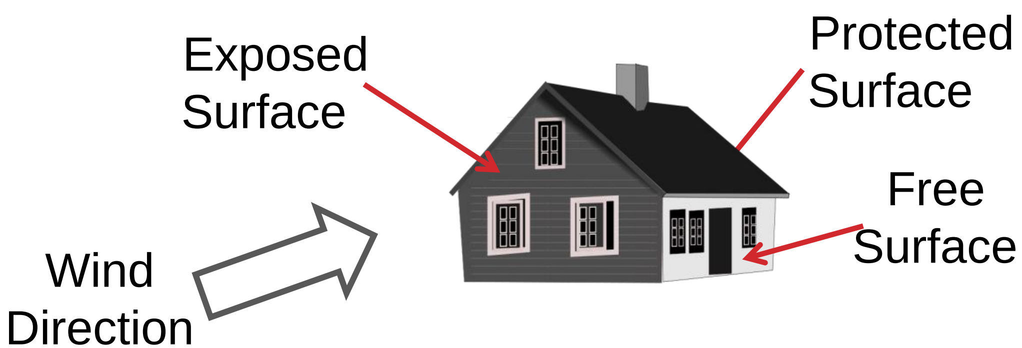
Air infiltration coefficient (R)

The dimensionless **air infiltration or penetration coefficient** expresses the complexity of the internal structure of the building and the relative patterns of air movement, and depends on the ratio of the surface area of the external openings to the internal ones.

Frame Material	External to internal opening ratio	R
Wood	< 3	0.9
	3 ~ 9	0.7
Metal or Artificial material	< 6	0.9
	≥ 6	0.7

Building Energy Efficiency Regulations
Location and Wind coefficient (H)

Wind Force	External surface position	Neighboring	
		Attached	Free
Normal	Protected	0.78	1.10
	Free	1.32	1.87
	Exposed	1.94	2.71
Strong	Protected	1.32	1.87
	Free	1.94	2.71
	Exposed	2.65	3.65



Typical air infiltration rates

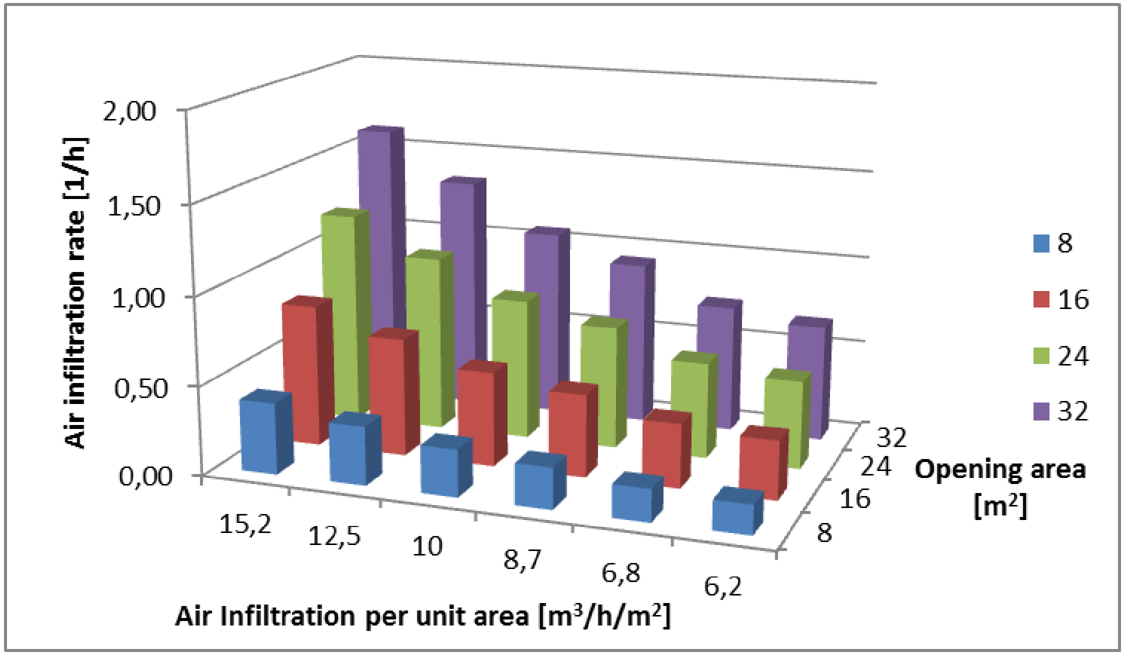
Assumptions: R =0.7, H= 1.87, Normal wind force & Free surfaces

Opening Type	Air infiltration [$m^3/(h/m^2)$]	
Wooden frame	Door	Window
Single glaze, non airtight or Without glaze, non airtight	11.8	15.1
Double glaze, sliding or opening. Without glaze, non certified airtightness	9.8	12.5
Double glaze, certified airtightness	7.9	10.0
Metal or Artificial material frame	Door	Window
Single glaze, non airtight or Without glaze, non airtight	7.4	8.7
Double glaze, sliding or opening. Without glaze, non certified airtightness	5.3	6.8
Double glaze, certified airtightness	4.8	6.2

Air infiltration example

Single House

- Total floor area: 100 m^2
- Indoor height: 3 m
- Total volume: 300 m^2
- Opening area 8-32 m^2



Factors affecting Radon in indoor air

Because of its relativity long half-life and lack of chemical activity Radon acts much like a stable pollutant.

Entry or Production rate

Indoor Radon Concentration

Rates of chemical or physical transformation or removal

Ventilation rate

Indoor radon and ventilation rate

Assuming that Radon enters an interior space from effectively internal sources at a fixed rate per unit volume, S_v:

$$\dot{I} = S_V - d \cdot I - \lambda_V \cdot (I - I_0)$$

Where $\lambda_v = Ventilation\ rate$

$I_0 = Concentration\ in\ outdoor\ air$

$d = decay\ rate\ of\ the\ gas$

At equilibrium, the indoor concentration is expressed from as:

$$I = \frac{S_v + I_0 \cdot \lambda_v}{\lambda_v + d}$$

Indoor Radon and ventilation rate

$$I = \frac{S_v + I_0 \cdot \lambda_v}{\lambda_v + d}$$

- For even low typical ventilation rate ~ 0.1 h^{-1} the decay rate of Radon (~0.0076 h^{-1}) can be ignored (d ~ 0).
- Outdoor concentration is usually very low (I_0 ~ 0).

$$I = \frac{S_v}{\lambda_v}$$

Indoor Radon and ventilation rate

- The model assumes Complete Mixing: mixing of Radon with indoor air is sufficiently fast and complete, the concentration of Radon is essentially uniform within a given room or floor of the house.
- It does not encompass time-dependent and interactive phenomena
- It does not cover the behavior of Radon decay products, whose concentration are determined by a number of interdepended reaction rates.

$$I = \frac{S_v}{\lambda_v}$$

However, it clearly illustrates that, for a fixed source strength, a decrease in the ventilation for energy saving purposes will result in a corresponding increase in the indoor concentration

Indoor radon and energy efficiency in the literature

- *Home energy efficiency and radon related risk of lung cancer: modelling study*. J.Milner et al., BMJ2013;348:f7493
- *Influence of energy-saving measures on the Radon concentration in some kindergartens in the Czech republic*. I. Fojtikova and K. Navratilova Rovaneska, Radiat. Prot. Dosim. 2014 Vol 160(1-3) 149-153
- *Dealing with the increased radon concentration in thermally retrofitted buildings.* M. Jiránek and V. Kačmaříková, Radiat. Prot. Dosim. 2014 Vol 160(1-3) 43-47
- *Indoor Radon problem in energy efficient multi-storey buildings, I.V. Yarmoshenko et al.* Radiat. Prot. Dosim. 2014 Vol 160(1-3) 53-56
- *What should the ventilation objectives be for retrofit energy efficiency interventions of dwellings?* J. Milner et al. Building Serv. Eng. Res. Techol. 2015 Vol 36(2) 221-229

Indoor Radon in Greece

Survey Type	Sample Size	Results (Bq m^{-3})	Reference
Residences	1277	G.M. 44 , G.S.D. 2.4	Nikolopoulos 2002
Residences	58	G.M. 41.1 , range 11.3-167.3	Papaefthymiou 2003
Workplaces	561	G.M. 106 , range 29-695	Clouvas 2007
Schools in high radon areas	77	A.M. 231 , range 45-958	Clouvas 2009
Residences and workplaces	295+76	G.M. 86, Range 5-958	Clouvas 2013
Residences in a high radon area	30	up to 1500	Kourtidis 2015
Workplaces	42	AM. 95 , S.D. 51	Papachristodoulou 2010

Indoor Radon in Greece - literature

- *Radon survey in Greece – risk assesment. D. Nikolopoulos et al.,* JER 2002, 63:173-186
- *Indoor Radon levels and influencing factors in houses of Patras, Greece.* H. Papaefthymiou et al., JER 2003, 66:247-260
- *Pilot study of indoor radon in Greek workplaces.* A. Clouvas et al., Radiat. Prot. Dosim. 2007, 124(2):68-74
- *Indoor radon measurements in areas of northern Greece with relatively high indoor Radon concentrations.* A. Clouvas et al, Radiat. Prot. Dosim. 2009, 136(2):127-131
- *Exposure to indoor Radon and natural gama radiation in public workplaces in north-western Greece.* C. Papachristodoulou et al., Radiat. Meas. 2010, 45:865-871
- *Follow-up study of indoor radon in Greek buildings.* A. Clouvas et al., Radiat. Prot. Dosim. 2013, 157(2):291-297
- *Radon and radioactivity at a town overlying Uranium ores in northern Greece.* K. Kourtidis et al., JER 2015, 150:220-227

Educational needs for engineers

- Engineers involved in building energy efficiency improvements cannot be expected to be fully competent to deal with Radon issues without assistance.
- As a baseline, engineers performing energy efficiency audits should be provided with :
  - Awareness of the issues and competent authorities (GAEC)
  - Guidance for accessing more specialized resources

Undergraduate Education

The Nuclear Engineering Department of the School of Mechanical Engineering teaches three elective courses that provide specialized knowledge for understanding Radon indoor behavior.

- Radiation Protection and Dosimetry
- Nuclear Measurement Systems
- Radio-environmental Analysis and Protection

The Department also participates in an inter-school course, including topics related to radiation protection and Radon:

- Environment and Development

Diploma Dissertations

Students with an interest in Radon can receive further training as part of their final year Diploma Dissertation, typically including experimental work:

- *Calibration experiments for the determination of Radon in air using adsorbing materials and liquid scintillators* (A. Dalaka, 2013)
- *Construction and calibration of a simple active detector for Radon concentration based on the ionization chamber principle* (S. Dimou-Sakellariou, 2010)
- *Geostatistical mapping of the concentration of indoor Radon in dwellings in the Peloponnese* (H.Moiras, 2008)
- *Calibration of adsorbing material canisters for the measurement of Radon concentration in air at different levels of relative humidity* (I. Paschalides, 2008)
- *Calibration of activated charcoal canisters for the measurement of indoor Radon concentration* (G. Marinakis, 2007)
- *Calibration of a Radon in water measurement set-up and application on drinking water samples* (I. Yfantis, 2003)
- *Modelling of Radon exhalation from the ground* (A. Nikoglou, 1999)

Post-graduate Education

The Nuclear Engineering Department also participates in post-graduate courses at NTUA:

- Physics and Technological Applications
- Environment and Development

Since 2005, NED-NTUA has also participated in a biannual IAEA PGEC on Radiation Protection and the Safety of Radiation Sources

Post-graduate Dissertations

Post-graduate students can also perform Dissertations on topics related to Radon at NED-NTUA

- *Calibration and application of methods for Radon in water concentration measurements* (M.Pinjuh, 2015 – IAEA PGEC)
- *Development of a method for Radon determination using passive detectors* (P. Kontakou, 2011, MSc Dissertation)
- *Determination of the concentration of indoor Radon using passive detectors* (L.Elmalis, 2011, MSc Dissertation)

Conclusions and suggestions

- Greek Building Energy Efficiency Regulations have for the first time instituted specific efficiency requirements for new buildings.
- The new efficiency requirements will lead to increased air tightness of buildings.
- An increase in indoor Radon concentrations is expected as a consequence, the extent of which should be studied further.
- Possible negative consequences on Radon concentration should be taken into account when planning efficiency improvements.
- NED-NTUA is actively involved both in research activities and in educating Greek engineers on Radon topics.