Energy in Buildings and Communities Programme

Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO)

How do we design and realize robust retrofitting with low energy demand and life cycle costs, while controlling risk levels for performance failure?

Carl-Eric Hagentoft
Operating agent (OA)

Start : April 2010
Ends: 2014

Presentations

Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost
Carl-Eric Hagentoft, Sweden

Why risk assessment and who should do it?
Andreas Holm, Germany
Achilles Karagiozis, USA

How to do it? Frame work and examples.
Angela Sasic, Sweden
Carsten Rode, Denmark

Monte Carlo and other stochastical methods – Are we playing roulette?
Hans Janssen, Belgium
Staf Roels, Belgium

Nothing is better than the data filled in!
Nuno Ramos, Portugal
John Grunewald, Germany

The IEA is an autonomous organization which works to ensure reliable, affordable and clean energy for its 28 member countries and beyond.
The IEA's four main areas of focus are:

- energy security
- economic development,
- environmental awareness
- engagement worldwide

And 25 Topics:
Energy efficiency, solar, geothermal,…

IEA: International Energy Agency

+Brazil and Estonia

Background

Improving the energy efficiency is often the main focus.

Adding insulation and changing the air and vapor tightness results in a different building envelope.

Complex interaction between building envelope, building services, external climate and the users.

As a result retrofitting measures not only often do not meet the energy targets; they also result in performance failures.

The *scope* of the work:

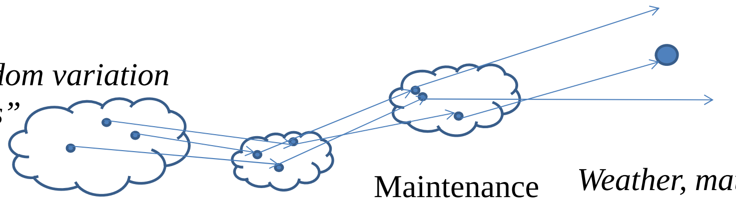
To develop and provide decision support data and tools for energy retrofitting measures leading to substantial upgrading.

The tools will be based on probabilistic methodologies for prediction of energy use, life cycle cost and functional performances.

- Energy
- Thermal comfort
- Performances:
  - U-values, Airtightness
  - Durability (frost, rot, mould and algae growth)
- Cost

Probabilistic approach

"Random variation clouds"



Production

Maintenance operation

Weather, material properties, exposure to spores, human behavior,…

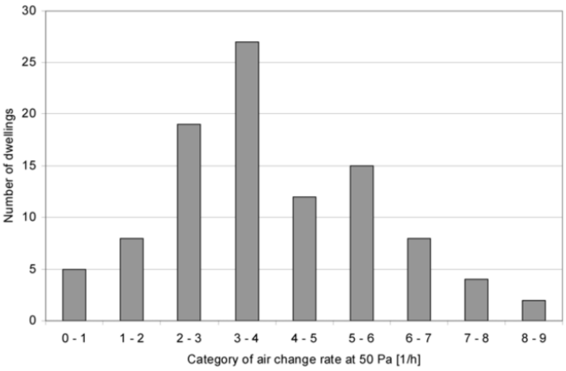
Examples of random variations in:

Workmanship initial conditions of material,…

Indoor moisture sources, internal gains airing, aging of material, cracks in façades,…

Example of Random variations

Performance -Air tightness
at 50 Pa of 100 timber-framed Finnish buildings
built after year 2000



Impact of airtightness:

- •Energy
- •Thermal comfort
- •Durability -Moisture safety
- •Indoor air quality
- •…

Case Studies

- Denmark
  - – Detached residential

- Portugal
  - – Social housing

- Sweden
  - – Multifamily residential

Why Risk Assessment and Who should do it?

Andreas Holm
Achilles Karagiozis

Example: Interior Insulation

Risks:

- Moisture damages: mold, frost
- Insufficient U-values
- Complex detailed solution
- Exhaust of harmful substances => indoor air quality (EPS, XPS, PUR)
- Fire protection
- …

Benefits

- Reduce heat loss
- Installation independent of outer weather conditions
- Appearance of the façade not affected
- Sometimes the only possible solution when building is under monumental protection
- Faster heating up
- Uneven wall surfaces can be adjusted

Interior Insulation Challenges

Damage connected with interior insulation

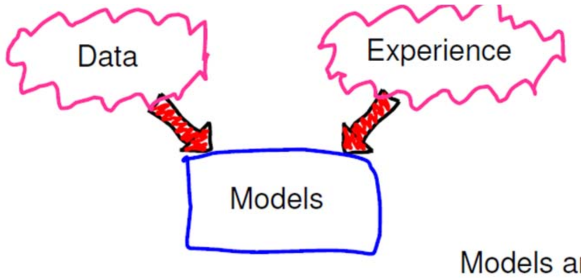
Intention of this Annex is to Quantify/Prevent Failures in Retrofit Applications

Questions that Decision-Makers and Stakeholders Typically Ask *(Or should ask!)*

- How well do we know these numbers/expected performances?
  - What is the precision of the estimates?
  - Is there a systematic error (bias) in the estimates?
  - Are the estimates based upon measurements, modeling, or expert judgment?
- How significant are differences between two alternative designs?
- How significant are durability trends over time?
- How effective are proposed thermal and moisture control or management strategies?
- What is the key source of uncertainty in these numbers?
- How can uncertainty be reduced?
- How can climate factors impact long-term and short-term performance

In a Perfect World ?

Building Scientists/Physicists
in a perfectly known world



Uncertainty

WHY ?

Models are not precise

Data are not sufficient

Natural variability

Experience is subjective

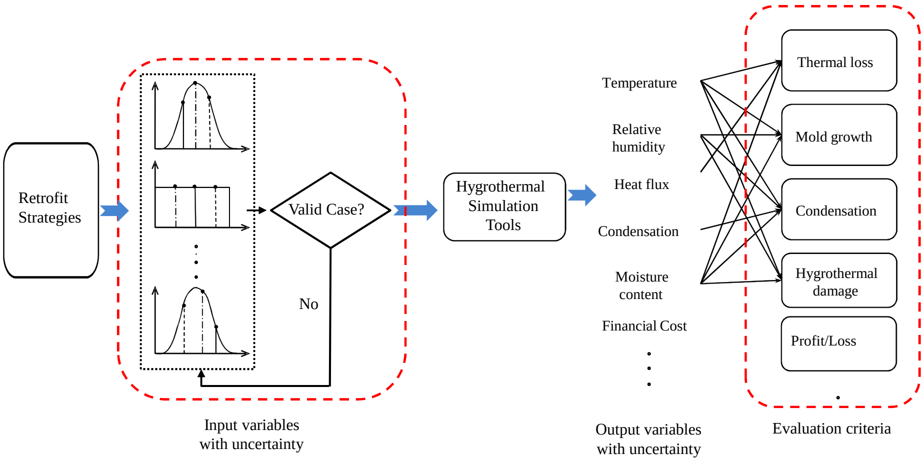
What to do?

Hygrothermal conditions within a construction and the building depends on a large number of factors - these should be accounted for!

This may introduce significant uncertainties in the results.

Increasing demand exists to define more realistically processes which also include the element of uncertainty.

Fundamentals for a proper probabilistic analysis -What we can do!



When is Probabilistic Analysis Needed or Useful?

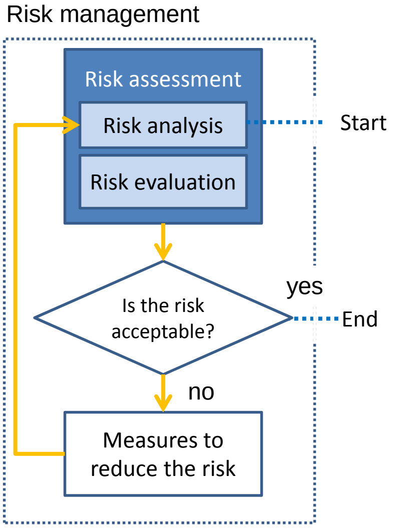
- Consequences of poor or biased estimates are unacceptably high
- Cost of remediation or intervention is high
- Significant equity issues are associated with variability

- A usually conservative screening level analysis indicates a potential concern, but carries a level of uncertainty
- Uncertainty stems from multiple sources

- Scientific credibility is important
- Obligation to indicate what is known and how well it is known

Dr. Frey

Risk management and Risk assessment



- Risk assessment should be preferably performed by experts.
- Renovation projects may involve risks for which expert knowledge is lacking.
- We can build-up knowledge while performing risk assessment.
- A framework helps in performing the assessment methodically and transparently (well documented)

Who are the Stakeholders -Who will use our findings?

- Specialized Architects/Engineers
  - They want to address design issues/improvements
  - Want to optimize energy performance
  - → Requirement: Highly trained individuals
- Developers/ESCO's, Government: Federal & Municipalities
  - Understand the economics
  - Understand risk implications
  - Want to understand cost of failures and future costs to society

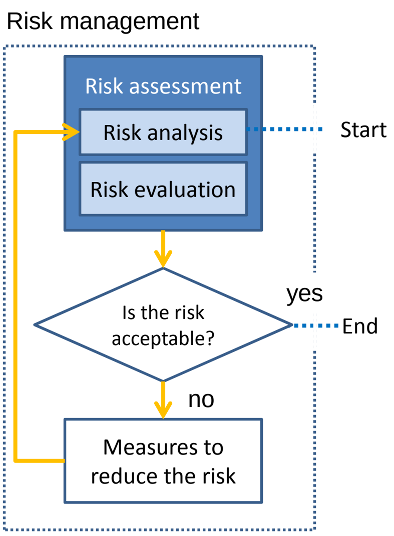
"Absolute certainty is a privilege of uneducated minds-and fanatics. It is, for scientific folk, an unattainable ideal“

Cassius J. Keyser

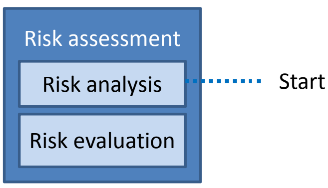
How to do it?
Frame work and examples

Angela Sasic Kalagasidis
Carsten Rode

Risk assessment - relation to ByggaF



Framework includes questions and actions that guide you through the assessemnet



- What is to be retrofitted?
- What is the aim of the retrofit?
- Desired values and consequences?
- What are the renovation strategies?

Risk analysis

- What is known about the chosen renovation strategies?
- What causes deviations?
- Qualify and quantify the deviations

Risk evaluation

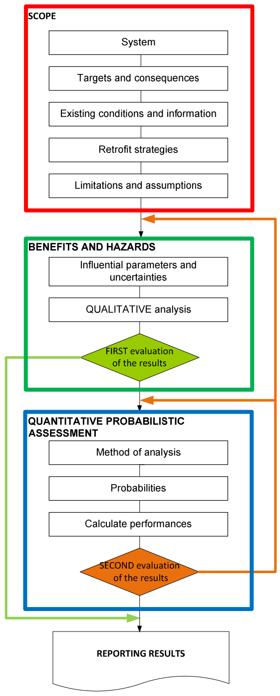
- How well does the renovation strategy meet the purpose of the renovation?
- Any limitations with the recommended renovation?

The Framework as a flow chart

Different sections and loops.

Outgoing loops mean quick 'exit' , i.e. when the assessment shows too high or too low risk.

Backward loops – that's usually a trouble, i.e. mistake made in the assessment process

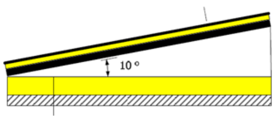


Example: additional insulation of a cold attic in a multi-story building

Desired values …
- Heat loss reduced by 50%
- Mould free attic (MGI<1)

and consequences
- Higher cost of heating, lower energy grading of the building
- Mould in the attic – cost of reparation

Retrofit strategies



Alternatives	1	2	3	4	5	6
Concrete floor	X	X	X			
Timber framed floor				X	X	X
Insulated floor (at least 200 mm)	X	X	X	X	X	X
Insulated roof (optional)		X	X		X	X
20 mm wide ventilation openings along roof eaves	X	X		X	X	
Ventilation through gable vents²			X			X

Performance criteria

- U-values for construction parts
- Heat loss through thermal bridges
- Indoor temperature and relative humidity
- Minimum / maximum air change rates
- Critical moisture in the construction materials
- Mould growth index
- Number of freezing/thawing cycles

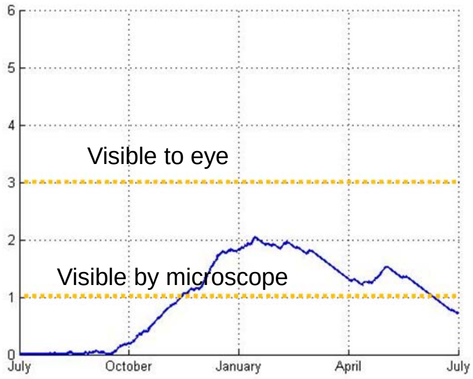
Source of image: internet

Good performance criteria are important

Critical moisture level according to BBR 6:52 is too rigid

If the critical moisture level for a material is not well-researched and documented, a relative humidity (RH) of 75 % shall be used as the critical moisture level.

Mould growth index – MGI is a well-researched criterion for wooden constructions



Knowledge building process – what improves the desired performance

- Available expert knowledge
- Measurements and in-situ tests
- Simulations

In this example – an expert can list a number of influential parameters

1. Building height
2. Area of the attic
3. Leakage area in the attic floor
4. Insulation thickness in the attic floor
5. Insulation thickness in the roof
6. Attic ventilation
7. Indoor moisture excess
8. Indoor air temperature
9. Initial moisture content in the wooden underlay
10. Climate year…

How to qualify and quantify the spread?

- Known spreads
- Imposed spreads
  - filling the gaps in available knowledge by simulations
- Testing scenarios – more examples in the next presentation

In this example:

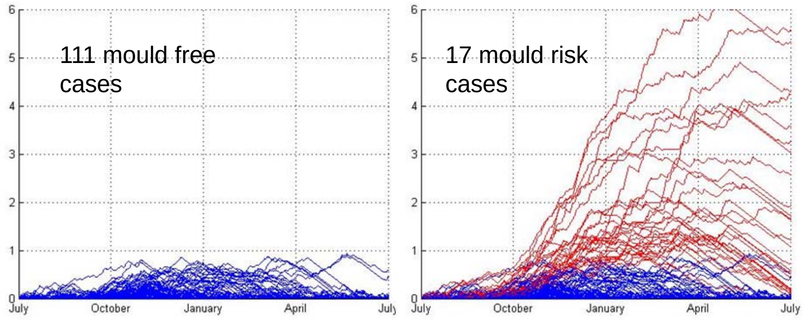
1. Building height
2. Area of the attic

3. Leakage area in the attic floor

…

Evaluation of the spread

- Examples of results



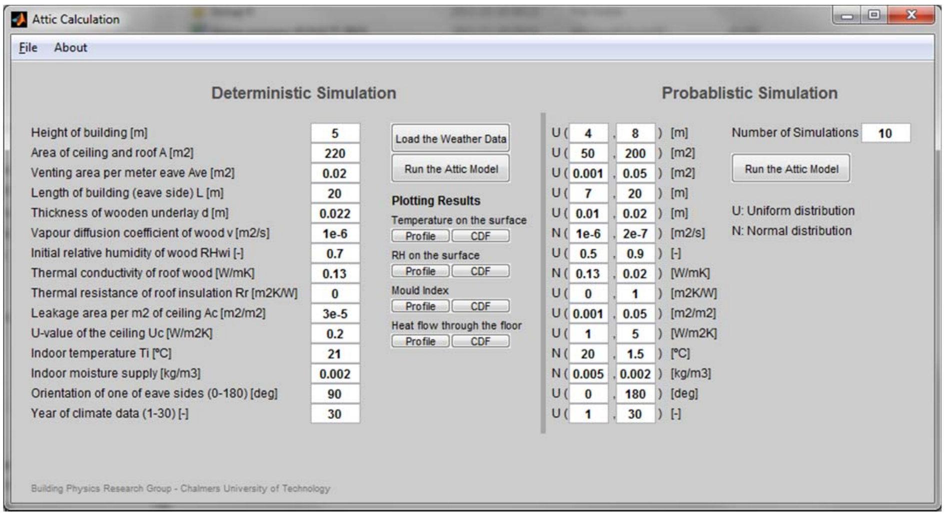
- Risk = 17/128=13% (reliability is 87 %)

What is available?

- Different forms of the framework to meet different user preferences: researchers and practitioners
- Several examples of risk assessments
- Description of performance criteria
- Case studies for inspiration
- Ready-to-use caculation tool SimpleAttic

(Available for free downloading from www.byggnadsteknologi.se)

Ready-to-use cacluation tool SimpleAttic
(www.byggnadsteknologi.se)



Monte Carlo and other stochastical methods
Are we playing roulette?

Hans Janssen
Staf Roels

Annex 55 Subtask 2 — Probabilistic tools

Intro: Application example

❖ Cold attic refrofit strategy *for a neighbourhood of 237 units*

Characterisation of building and attic characteristics for estate:

	avg.	min.	max.
o building height (m)	6	4	8
o surface area (m²)	125	50	200
o roof orientation (°)	90	0	180
o eave vents (m²/m)	2.5	0.1	5
o eave length (m)	13.5	7	20
o roof insul. (m²K/W)	0.5	0	1
o ceiling leaks (cm²/m²)	30	10	50
o U of ceiling (W/m²K)	3	1	5
o indoor temp (ºC)	20	18	22
o moisture exc. (g/m³)	5	2.5	7.5

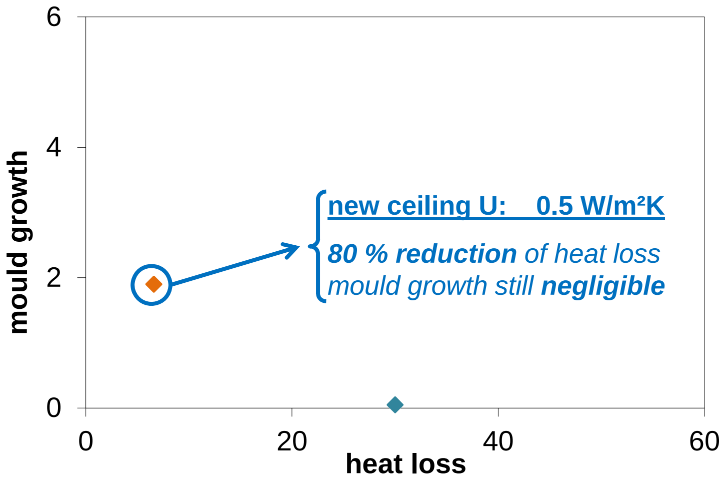
perform. criteria: heat loss & mould growth

Annex 55 Subtask 2 — Probabilistic tools

Step 0: deterministic optimisation

❖ Heat loss & mould growth *for average dwelling characteristics*

Current U: 3.0 W/m²K New U: 0.5 W/m²K

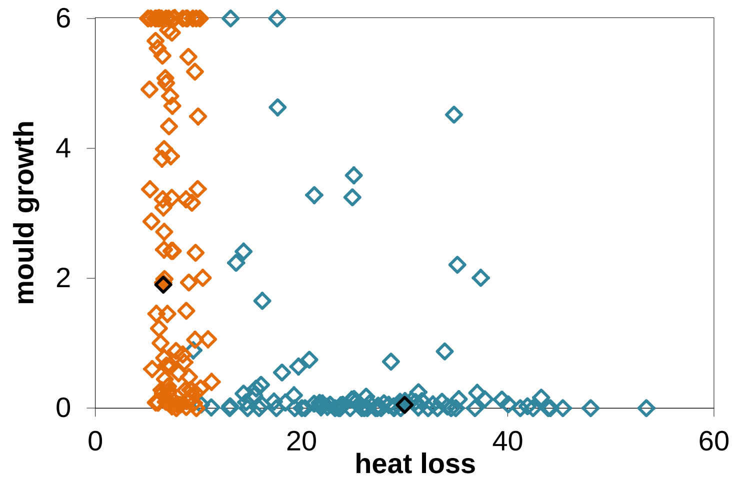


Annex 55 Subtask 2 Probabilistic tools

Step 1: uncertainty quantification

- Heat loss & mould growth *for range of dwelling characteristics*

Current U: 1.0 – 5.0 W/m²K New U: 0.3 – 0.7 W/m²K



Annex 55 Subtask 2 Probabilistic tools

Step 1: uncertainty quantification

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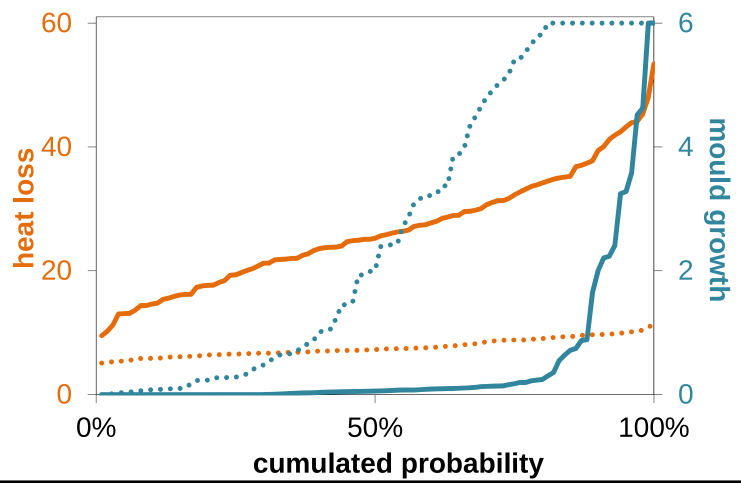
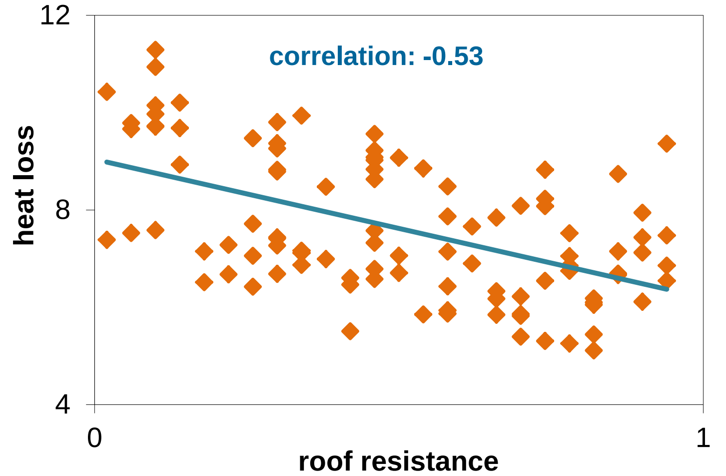


Annex 55 Subtask 2 — Probabilistic tools

Step 2: sensitivity analysis

❖ Impact of building characteristics *on the potential heat losses*

New U: 0.3 – 0.7 W/m²K — impact of roof resistance

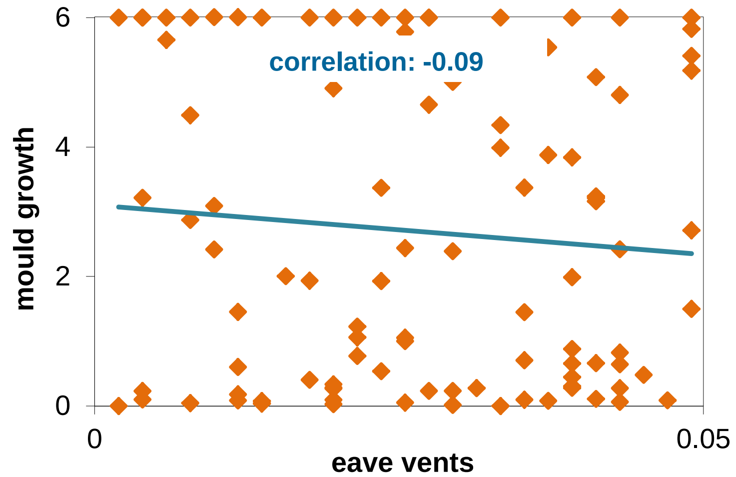


Annex 55 Subtask 2 — Probabilistic tools

Step 2: sensitivity analysis

❖ Impact of building characteristics *on potential mould damages*

New U: 0.3 – 0.7 W/m²K — impact of eave vent area

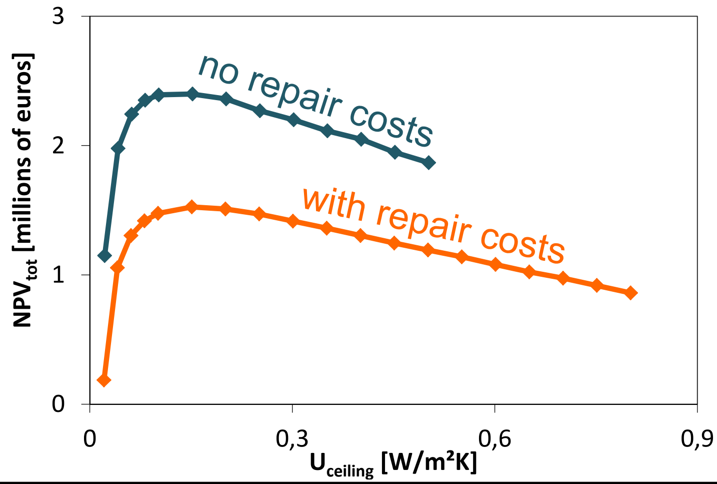


Annex 55 Subtask 2 Probabilistic tools

Step 3: economic optimisation

❖ Cold attic design optimisation *based on economic gains/costs*

Net present value of retrofit including damage expenses

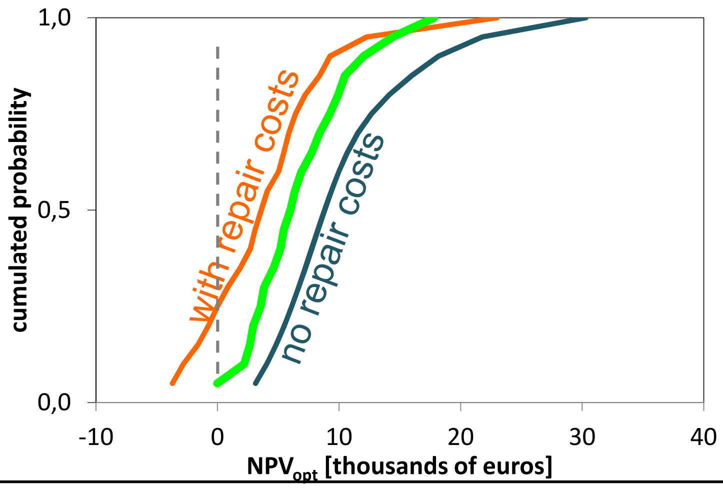


Annex 55 Subtask 2 Probabilistic tools

Step 3: economic optimisation

❖ Cold attic design optimisation *based on economic gains/costs*

Net present value of retrofit **including ceiling leakage repair**

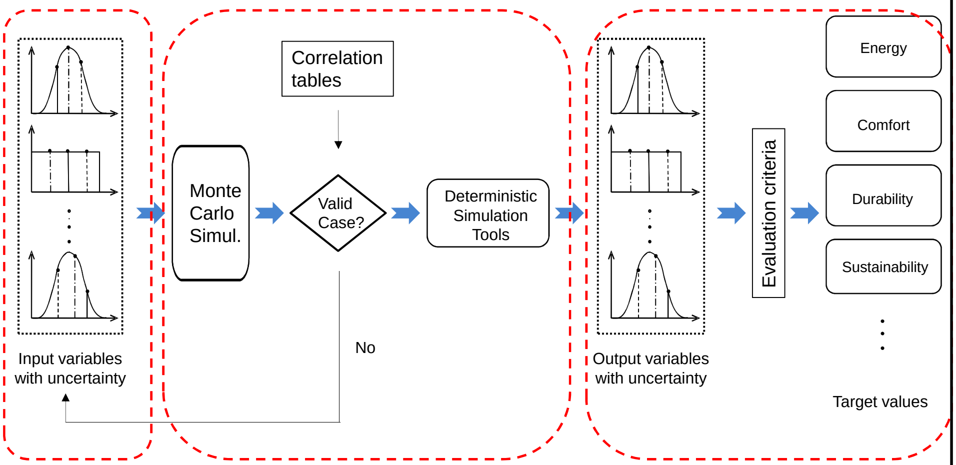


Nothing is better than the data filled in!

Nuno Ramos
John Grunewald

Introduction

Uncertainty in
- climate, ground properties, exposition
- geometry, construction, air tightness, surface and material properties
- occupancy, target temperatures, ventilation rates



Stochastic data:

- Envelope
- Ventilation and airtightness
- Indoor loads
- Weather

Example:

❖ Cold attic refrofit strategy *for a neighbourhood of 237 units*

Characterisation of building and attic characteristics for estate:

	avg.	min.	max.
building height (m)	6	4	8
surface area (m²)	125	50	200
roof orientation (°)	90	0	180
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U of ceiling (W/m²K)	3	1	5
indoor temp (°C)	20	18	22
moisture exc. (g/m³)	5	2.5	7.5

perform. criteria: heat loss & mould growth

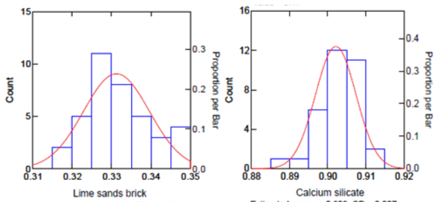
Envelope - Material properties statistical description

Minimum Input Information

Hygrothermal basic parameters							
Parameter	**Symbol**	**Unit**	**Mean**	**StdDev**	**Min**	**Max**	**Remarks**
Bulk density	ρ	[kg/m³]	1741.0	44.0	1657.2	1787.5	
Specific heat capacity	c	[J/kgK]	939	72.7	868	1092	
Thermal conductivity	λ_{dry}	[W/mK]	0.656	0.117	0.543	0.871	
Open Porosity	θ_{por}	[m³/m³]	0.352	0.011	0.336	0.375	
Capillary saturation	θ_{cap}	[m³/m³]	0.254	0.011	0.231	0.266	
Dry cup value	μ_{dry}	[---]	18.0	05.8	08.6	24.5	
Water absorption coefficient	A_w	[kg/m²s$^{0.5}$]	0.175	0.047	0.107	0.227	
Water Retention (Desorption)							
Arguments			**Mean**	**StdDev**	**Min**	**Max**	**Remarks**
pc [hPa]			θ_l [m³/m³]				
0			0.332	0.016	0.313	0.357	
30			0.320	0.017	0.297	0.351	
60			0.318	0.016	0.296	0.345	
150			0.308	0.016	0.289	0.335	
300			0.295	0.032	0.232	0.334	
600			0.282	0.038	0.212	0.334	
900			0.262	0.042	0.206	0.316	
2000			0.163	0.047	0.100	0.221	
4000			0.093	0.037	0.047	0.146	
8000			0.075	0.034	0.041	0.137	
14000			0.062	0.028	0.030	0.120	
Sorption Isotherm (Desorption)							
Arguments			**Mean**	**StdDev**	**Min**	**Max**	**Remarks**
φ [%]			θ_l [m³/m³]				
97.4			0.0250	0.0130	0.0037	0.0427	
96.0			0.0182	0.0112	0.0033	0.0380	
90.0			0.0122	0.0060	0.0028	0.0185	
84.7			0.0097	0.0049	0.0025	0.0164	
75.4			0.0062	0.0032	0.0024	0.0111	
58.2			0.0043	0.0016	0.0019	0.0060	
43.2			0.0032	0.0016	0.0013	0.0053	
32.9			0.0026	0.0016	0.0008	0.0051	

Additional Input Information

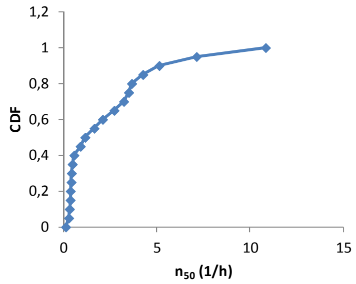
Water vapour permeability							
Arguments			**Mean**	**StdDev**	**Min**	**Max**	**Remarks**
φ_{inside} [%]	$\varphi_{outside}$ [%]		μ [-]				
5.0	30.0		18.0	5.8	8.6	24.5	DryCup
96.0	82.0		13.7	4.6	8.5	20.8	WetCup
Liquid water conductivity							
Arguments			**Mean**	**StdDev**	**Min**	**Max**	**Remarks**
θ_l [m³/m³]	mean pc [Pa]		K_l [s]				
0.33			3.1E-09	3.4E-09	8.6E-10	1.1E-08	

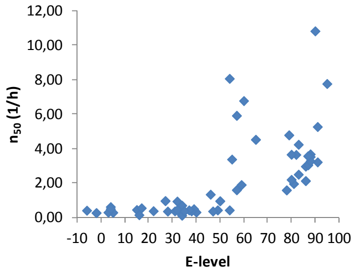


Lime sands brick
Estimated: mean = 0.33, SD = 0.008
Kolmogorov-Smirnov test statistic =0.11
Shapiro-Wilk test statistic for normality = 0.969
P-value = 0.36

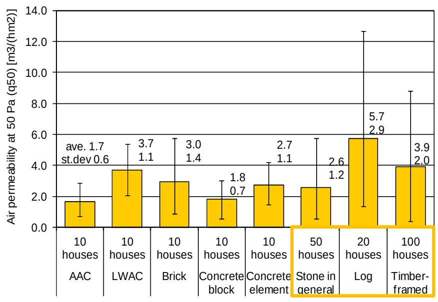
Calcium silicate
Estimated: mean = 0.903, SD = 0.007
Kolmogorov-Smirnov test statistic =0.129
Shapiro-Wilk test statistic for normality = 0.95
P-value = 0.12

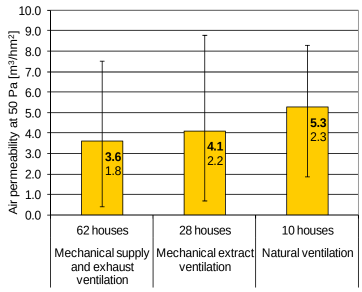
Airtightness – description and correlations

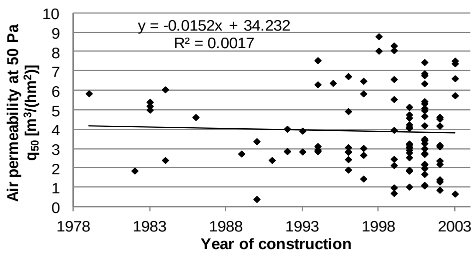


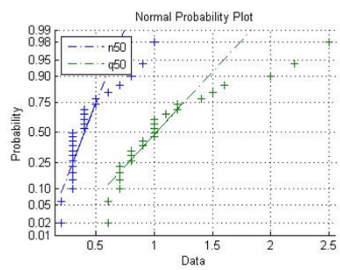


Airtightness – description and correlations

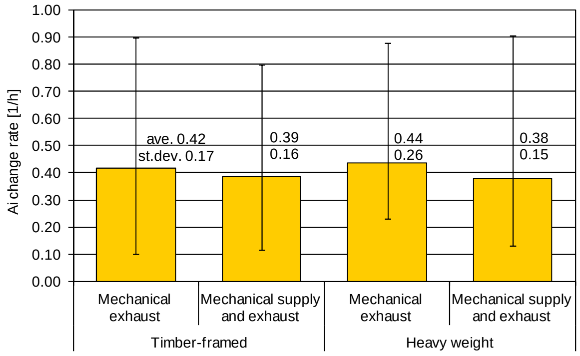




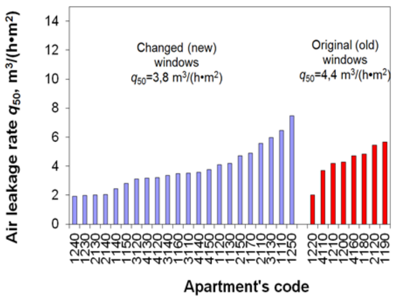


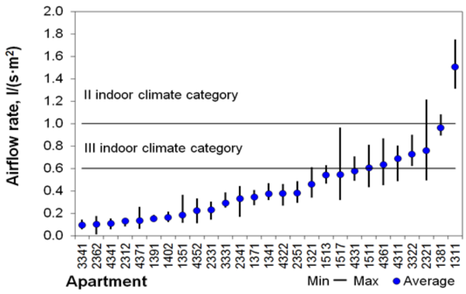


Ventilation – description and correlations

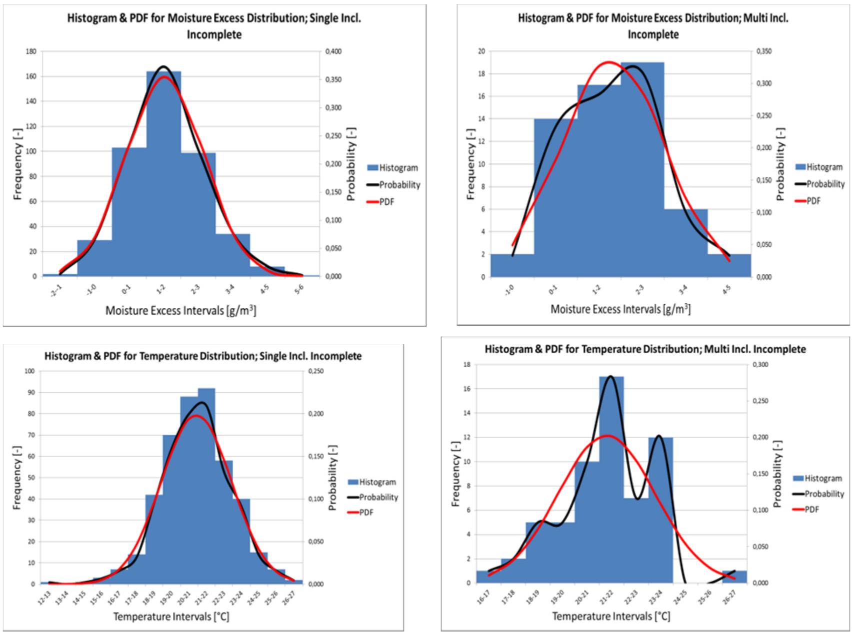


Ventilation – retrofitting results analysis

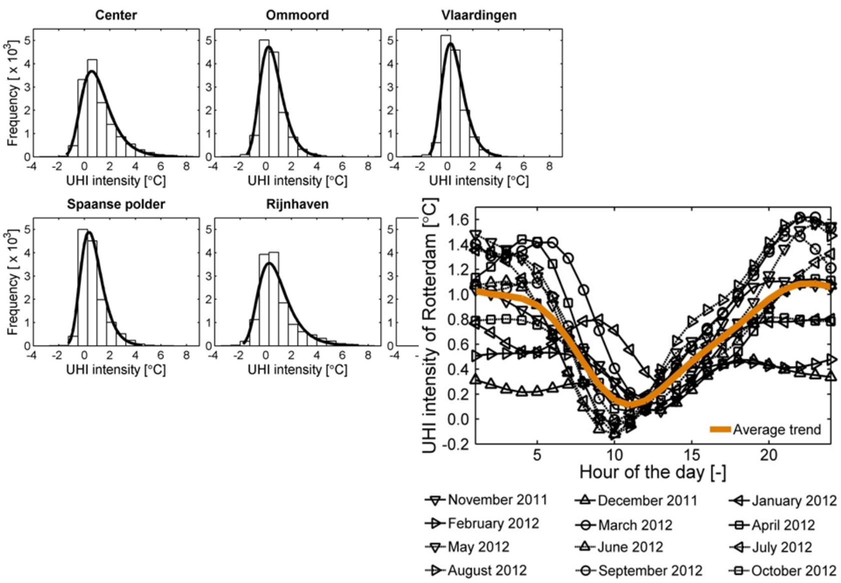




Moisture loads – statistical description strategy



Weather – the urban heat island effect



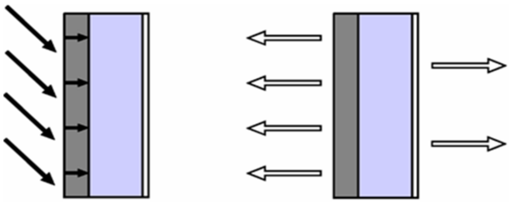
Thanks!

Reports will be available during the end of 2014!

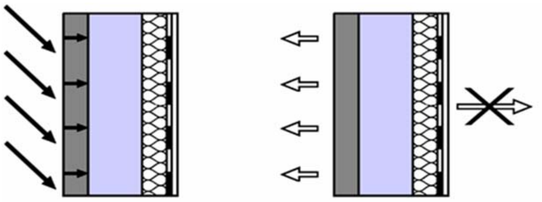
Time for Questions!

Interior Insulation Challenges

Before



After



Uncertainties must be considered in the decision making throughout all phases of the life of an construction **(Faber)**

Definition of Risk

Risk:

- the likelihood of a specific effect within a specified period
- it is a complex function of ***probability***, ***consequences*** and ***vulnerability***

Definition of Risk

The risk associated with a given activity:

$$R_A = \sum_{i=1}^{n_E} R_{E_i} = \sum_{i=1}^{n_E} P_{E_i} \cdot C_{E_i}$$

- risk contribution R_{Ei} from event E_i
- event Probability P_{ei}
- consequences of the event C_{Ei}