Hygrothermal Analysis for Retrofit Design

Presented by:
Achilles Karagiozis, Ph.D.

How to address Energy Efficiency using Building Science
Presenter – Achilles Karagiozis

Director of Building Science
Owens Corning, Sustainability Group

Questions? Contact  Achilles.Karagiozis@owenscornig.com
Why is Retrofit Different?

- Retrofit Challenges
- Diversity of Retrofit Issues
- Tools and Current Information
- Methodology and Solutions (2-examples)
- IEA Annex 55
- Conclusions
Retrofit here? What do you think?

Needs a Good Dose of Building Science

Infrared Thermography
Past Approach

Trial and Error

Attention to Detail
but
Little Building Science

Worked until:

- Enhanced Comfort Requirements
- Energy Conservation
- Material started to Change
What is different with RETROFIT?

- Limited past knowledge
- One solution does not fits all (Envelope + Climate)
- Client is different not Builder but owner/contractor
- Level of Building Science Understanding (lower)
- Workmanship/crew is different
- Environmental loading will change
- Easy and difficult retrofits, wide range of challenges
- More unknowns …. Larger risk for failures
- More Economics based
European Prospective

Sweden, Finland, and Norway started major retrofit activities 1986 to now

- Moisture problems
- Indoor air quality (health implications)
- Durability

Germany, Belgium
- Same IAQ, Moisture Issues
- Not achieving retrofit performance
Unknowns in RETROFIT

- Envelope Assembly unknown (NO MANUAL yet)
- Prime properties (Trouble with new, near impossible with old data)
- Aging of materials (Mortars, WRB, paints, plasters..)
- Initial Conditions
- Sub-systems ?
Wood has Changed

Stucco has changed

Building Papers have changed

What used to be?

Seattle Roof
Additional Unknowns

Exterior Loads

Application Issues

Density Variations

Figure 4. Vertical density profiles of specimens scanned by X-ray QMS Density Profiler.
Interior Loads based on Climate

Variations in time and location

Relative Humidity [%]

Florida  New York  Oregon  Washington

Living
Winter  Spring  Summer  Fall
Interior Loads based on Climate

Variations in time and location

Temperature [°C]

<table>
<thead>
<tr>
<th>Living</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oregon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HUD/Steven Winters/ORNL
Building Science Approach

- Define Physics
- Define Load Inputs
- Define Material
- Define Construction Systems & Sub-Systems
Moisture Design - Deterministic Tool

Use Standard ASHRAE 160 (Criteria for Moisture-Control Design Analysis in Buildings)
HYGROTHERMAL MODELS

STEADY STATE

1-D

Fields: \( P_v, T \), Constant Properties

Fields: \( P_v, T \) Variable Properties

Fields: \( P_v, T, P_{suc} \) Variable Properties

2-D, 3-D

Fields: \( P_v, T \), Constant Properties

Fields: \( P_v, T \) Variable Properties

Fields: \( P_v, T, P_{suc} \) Variable Properties

3-D

Deterministic

Fields: \( P_v, T, P_{tot}, P_{suc} \), Variable Properties

Stochastic

Fields: \( P_v, T, P_{tot}, P_{suc} \) Variable Properties

Stochastic Material Properties

Stochastic Boundary Conditions

Building System and Sub-System Effects

Variable Properties
Inquiring Minds Want to Know…

What is **MOST** Economical?

What is more important to improve my home first?

How does our home compare to an energy-efficient home?

How **long** will it take to re-coup my investment?

Will my house be **healthy** and **durable**??
Two recent examples: replaced FG with other insulation systems

- Use of spray foam to seal and insulate wall with higher R-value in Northwest Pacific

- Use of spray cellulose in Cold Climate (Michigan)

Attend the XI Thermal Conference for more details (Both cases have experimental field Data)
Use of Closed Cell Spray Foam (Northwest)

Stucco Cladding, 2 Bldg Paper 60 min, OSB, Closed Cell, GYP, 10 Perm Paint

Net Accumulation with time

Net Drying with time

3 Years of Analysis
• **Use of Blown Cellulose (Cold-Climate)**
  40 % by mass (2.5 lb/ft3)

**Hygrothermal Performance**

**Retrofit Risk of Initial Conditions**

![Time Series Plot of Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, ...](image)

- **Variable**:
  - Jan
  - Feb
  - Mar
  - Apr
  - May
  - Jun
  - Jul
  - Aug
  - Sep
  - Oct
  - Nov
  - Dec

- **Time after installation, hour**

- **Moisture Content of OSB, % by weight**

**Detroit Michigan**
What Retrofit Analysis Needs

- Load based analysis
- Move from deterministic to probabilistic

NEW IEA Annex
Stochastic Approach

Stochastic runs: +/- 40%

Material Property Variability

Variable Material Properties

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

The RAP-RETRO mission is to answer the following question:

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

Start: Spring 2010 (4 years in total)

International Energy Agency
Energy Conservation in Buildings and Community Systems (ECBCS)

Carl-Eric Hagentoft
Improving the energy efficiency is often the main focus. (40 to 60% space heating and cooling)

Adding insulation and improving 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.
Difficult to design for 100% safety!

We can not double the thickness of the beam as in structural engineering!

(Except if we accept poor energy efficiency!)

We must design as safe as possible – accounting for the all uncertainties and for what could happen!
Probabilistic approach

“Random variation clouds”

Construction Retrofit

Maintenance operation

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

Examples of random variations in:

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

Workmanship

initial conditions of material, …
Energy Performance is Stochastic

Distribution of annual energy demand per square meter in 87 similar Swedish dwellings from the 80’s

![Bar chart showing distribution of kWh/m²](image)
Air Tightness is Stochastic

Performance - Air tightness at 50 Pa of 100 Wood frame Finnish buildings built after year 2000
Retrofit Energy is Stochastic

Performance - Thermal protection/U-values:
Measured U-values of a number of Belgian cavity walls.
Blue before retrofitting, red: after insulation retrofitting
The scope of the annex is to:

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.
The objectives of the annex are to:

- Develop a common framework for probabilistic assessment of energy retrofitting measures
- Develop and validate probabilistic tools for energy use, life cycle cost and hygrothermal performances
- Collect and analyze data in order to create stochastic data sets
- Apply and demonstrate probabilistic methodology on (at least) five real life case studies, with a focus on residential buildings
- Create guidelines for practitioners including assessment of common retrofitting techniques.
To build the work on the gained knowledge in building physics and to add risk assessment tools.

Input parameters

Stochastic models

Deterministic Core (today)

Assessments

Output - Performance

Output - Top level-reliability

Basically from previous annex (14,24,32 an 41)

Energy
LCC
Durability
Indoor environment
Distribution of life cycle cost for alternative design

An example of a decision support tool
**Subtask 1:** *Gathering of stochastic data*
- ST1.1 Energy, cost and performance
- ST1.2 Boundary conditions
- ST1.3 Material and building services
- ST1.4 Workmanship

**Subtask 2:** *Probabilistic tools*
- ST 2.1. Tools for probabilistic assessment
- ST 2.2. Validate probabilistic tools

**Subtask 3:** *Framework and Case studies*
- ST 3.1 Common framework
- ST 3.2 Characterization and collection of performance criteria, collected from standards and reference literature.
- ST 3.3. Evaluation of framework for assessment

**Subtask 4:** *Practice and Guidelines*
- ST 4.1 Listing of frequently used retrofitting technologies – benefits and risks
- ST 4.2 Guidelines for how to use the developed framework for risk assessment in practice
**Subtask leaders:**

Vasco Freitas and Nuno Ramos University of Porto, Portugal  
ST1

Staf Roels, KUL, Belgium, Hans Jansen, DTU, Denmark  
ST2
John Grunewald, Technische Universität Dresden, Germany  
ST2

Carsten Rode, DTU, Denmark  
ST3
Angela Sasic, Chalmers, Sweden  
ST3

Achilles Karagiozis, Oak Ridge National Laboratory, USA  
ST4
Andreas Holm, IBP Holzkirchen, Germany  
ST4
Conclusions

- Retrofit Analysis needs special tools
- One solution does not fit all (Envelope + Climate)
- Risk for failure is higher
- New IEA Annex 55 will jumpstart the probabilistic approach (Whole Building Hygrothermal Analysis)
- Start with SIV (Seal, Insulate and Ventilate) but do more