XII | DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Moisture Risks Assessment Related to Energy Retrofitting of Existing Buildings: Method and Case Studies

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ABSTRACT

Several surveys have revealed that most of the existing French buildings are still poorly insulated. The current rate of retrofitting is low (1%) but it is tending to accelerate to reach the announced objectives. The problem of internal moisture requires special attention during retrofitting operations. In strongly insulated and poorly ventilated buildings internal condensation can leads to the development of micro-organisms, materials degradations, discomfort and potentially health issues. The aim of the Humirisk project was to propose a renovation methodology in order to limit the moisture risks related to the building modifications. This paper describes a method that has been developed and discuses the results obtained from six case studies. The method is based on assessment of the building initial state according to several parameters (construction system, condition of housing units, behaviour of inhabitants, temperature, relative humidity, air permeability and diagnostic through infrared camera). The building is then split into several sub-systems and studied through a simplified Failure Modes and Effects Analysis (FMEA) in order to emphasize potential failure modes that would result from the retrofitting step. This modeling approach allows representing easily different configurations of buildings. Results of the different FMEAs can then be compared in order to propose a suitable retrofitting solution that takes into account the risks related to moisture.

KEYWORDS

Risks assessment,FMEA, energy retrofitting, moisture

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1 INTRODUCTION

Products and innovative systems are and will be designed to achieve the ambitious goals of reducing energy consumption in buildings. Their levels of performance will thus be particularly high, and they must be maintained over time to ensure the durability of the works and in compliance with essential requirements "for a reasonable economically service life " as stated in the Construction Products Directive.

So, the failure criteria of these retrofit packages must be studied with new eyes. What was previously assessed as minor degradation (less critical failures) will be most serious malfunctions of tomorrow regarding the new energy performance requirements. We must also take into account interactions between the different systems and products used in a retrofitting.

Failure Mode and Effect Analysis (FMEA) is a method that aims to identify the combination of events leading to the failure of a product. Previous works have shown that this approach is interesting for durability assessment of building systems [Talon, 2006]. The literature reports several approaches presenting guidelines for FMEA integration in the building sector as well as case studies [Talon et al., 2006]. For instance [Hans & al. 2007] used a common FMEA workflow involving products and method experts to assess durability of several inovative building systems.

The HUMIRISK [Abele & al. 2010] project aims to assess the consequences of a renovation on heat and moisture transfer and intend to demonstrate that a risk free renovation is possible. This requires to integrate the issue of durability and risk management at early conception stage.

In this objective, the FMEA approach has been adapted to include several components of building. Indeed the system has been defined to collect the various renewal actions (establishment of a ventilation system , change of windows, installation of insulation ...) and to list the events leading to a degradation both on the element themselves but also on others parts of the buildings. From this analysis failures scenarios have been highlighted. This study was managed by CSTB attended by several partners (ALDES, Saint-Gobain Isover).

The study is divided into different steps:

- Definition of functional generic block (wall, interior insulation, ventilation system,…)
- The selection of blocks and interfaces for defining housing in the initial state;
- The selection of blocks and interfaces for defining the unit after renovation;
- The definition of links between blocks;
- The definition of the functions of each of these blocks (functional analysis) and study of possible damage;
- The list of the final degradation related to the renovation for each block;
- Analysis of critical points related to the renovation;

2 SYSTEM ANALYSIS

The analysis of the system deals with the description, characterization and modeling of the studied product and its components. For our study the system which was studied was the building before renovation.
In this analysis we have defined the structural composition of the building (system boundaries, components, interfaces, binding modes), its environment, functions and errors, omissions, negligence suffered by the product during its construction process that can cause damages or failures during its operational phase.
This first step gives information about the structural condition of the building during its operational phase (before renovation) and its behavior in response to environmental contrains.

To meet the expectations of the study, that is to say to have a method to effectively assist innovation in the renovation with the problematic of moisture, we propose a new FMEA methodology.

The FMEA method requires a large investment for each new study as it is necessary to redefine the system with all its component. To be able to model and study more easily a building, we have split the building into different "generic blocks ". The 13 blocks created (ventilation system, heating system, interior insulation, ...) are showned in the system structural analysis. This simplification of the FMEA method allows to reuse these blocks without having to conduct a study on every detail of the building structural decomposition.

Each block is representing a portion of the building and is initially studied independently.

The blocks are the following:

- Ventilation system;
- Heating System;
- Technical jacket;
- Interior insulation;
- External insulation;
- External vertical walls;
- Roofing;
- Floor;
- Balcony / loggia / window sill;
- Window;
- Door;
- Outdoors;
- Service Parts;
- Living areas

3 DETERMINATION AND CHARACTERIZATION OF INTERFACES

The interfaces are modeled as mechanical connections (glued, welded, bolted, attached or single contact) between system components (e.g. The window is connected to the vertical wall with screws).

3.1 Functional analysis of blocks and bonds

The goal of functional analysis is to determine the overall system functions and the functions performed by its components and interfaces.

For this, key features of each block are identified, thus leading to the creation of a functional model of the studied building. This model will be used as a basis for failure effect identification. Indeed if one of the function is no more maintened the impact on the component and the system could be immediately identified trough relations between functions.

This step is crucial, but still difficult to carry out. Indeed the definition of the overall system functions gives the boundaries of the study and the determination of relevant failure modes is strongly depend on the quality of the functional description.

In our approach, functions are attibuted to the generic blocks previsouly defined, but also at the interface between blocks.
The table below shows the functions of blocks and their connections (table 1).

Table 1. Exemple of functions

Block 1	Block 2	Connection function
Ventilation system	**Heating system**	
extract the house contaminated air	to be safe (user safety)	
bring fresh air	to be safe (user safety)	
Ventilation system	**outside wall**	
Distribute air flow	stop air flow	remain in position
Distribute air flow	limit weathering flow	remain in position
limit outside noise	control noise flow	remain in position
be silent	control noise flow	remain in position
reduce heat losses	limit heat flow	remain in position
Distribute air flow	Esthetic	remain in position
Distribute air flow	limit noise flow	limit noise flow
Ventilation system	**Roofing**	
extract contaminated air	control weathering flow	limit weathering flow
provide fresh air	control weathering flow	limit weathering flow
Ventilation system	**under the window**	
Distribute air flow	stop air flow	remain in position
Distribute air flow d	limit weathering flow	remain in position
limit outside noise	control noise flow	remain in position
be silent	control noise flow	remain in position
reduce heat losses	limit heat flow	remain in position
Distribute air flow	being aesthetic	remain in position
Distribute air flow	limit noise flow	limit noise flow
Ventilation system	**window frame**	
Distribute air flow	stop air flow	remain in position
Distribute air flow	limit weathering flow	remain in position
limit outside noise	control noise flow	remain in position
be silent	control noise flow	remain in position
reduce heat losses	Limit heat flow	remain in position
Distribute air flow	being aesthetic	remain in position

4 QUALITATIVE ANALYSIS THROUGH FMEA

FMEA allows the identification and description of degradations modes and product failures.
For each block and its associated functions we seek to identify all potential degradations, their causes and consequences. This process is iterative and ends when all the failure scenarios are known.
The first step summarizes the damage caused by construction process, stage 1 corresponds to the initial state at the beginning of the exploitation phase which is not necessarily a stage without damage since it can integrate those due to errors in the construction process. The following steps identify the sequence of degradations, that is to say the scenarios of system failures. Examples of results obtained are presented in table 2 bellow.

Table 2. Excerpt from FMEA results.

	Function	Component	Cause	direct effect	indirect effect
1	air distribution	Ventilation system	airflow not or partially insured	Insufficient air turnover	Insufficient air quality / humidity
2	limiting outside noise	Ventilation system	noise	obstruction of the ventilation system	back 1
3	limiting functional noises	Ventilation system	noise	obstruction of the ventilation system	back 1
4	limit heat loss	Ventilation system	cold air / energetic losses feeling	obstruction of the ventilation system	back 1
5	extract the house contaminated air	Ventilation system	airflow not or partially insured	Insufficient air turnover	Insufficient air quality / humidity
6	provide fresh air (focuses on people)	Ventilation system	airflow not or partially insured	Insufficient air turnover	Insufficient air quality / humidity

5 FAILURES GRAPH

FMEA identifies all possible failure scenarios in a table. Therefore the table quickly becomes very large and make it difficult to visualize the scenarios.
To overcome this problem, results are ussully represented as failure event graphs. The graphs represent event-failure sequence and / or the concomitant degradation of components over time that lead to product failure (see figure 1).

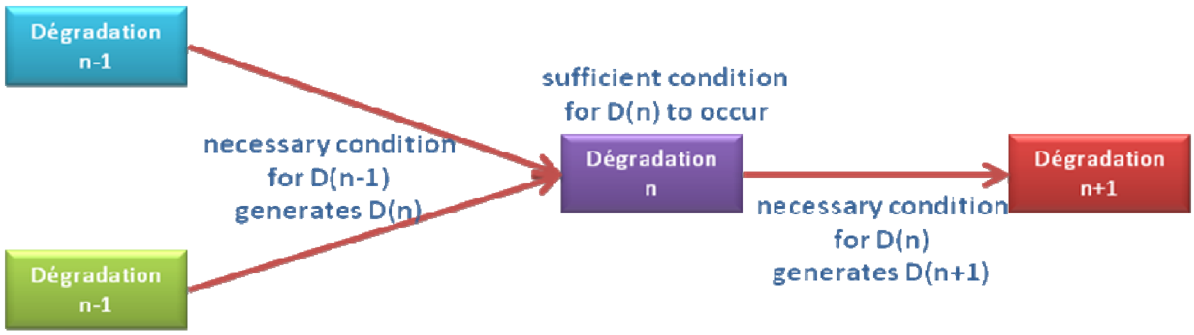

Figure 1. Convention adopted for reading failure graphs

The failures graphs construction is based on the same principle as the iterative development of the matrix of failure modes and effects analysis. They are composed of nodes and edges.
Nodes define : the name of the component or interface, the functions provided by this component or the interface and their modes of deterioration.

In addition, to support damage diagnosis, failures graphs can be useful for the analysis of potential malfunctions during the design phase, and the quality control provided for the different stages of the process (implementation, maintenance) or implemented for an existing product (operation, retrofitting).

6 MODELING THE CONFIGURATION AFTER RETROFITTING

Using the generic blocks presented earlier, we can modelize the initial configuration of the building before the renovation.
Changes related to the renovation are then integrated as, for instance an exterior insulation or the installation of a ventilation system.

The risk analysis shows that the presence of a balcony or loggia or window sill may create a thermal bridge if the area is not properly treated. Figure 4 show that this failure should creat the Loss of overall thermal performance.

The photo below shows that the insulation does not return on the window sill, this is leading to the presence of a thermal bridge. Cracking of the coating can also create points of water infiltration (see Fig 2).

Figure 2. Treatment of windowsills in a renovation

This thermal bridge itself can cause a cold spot. The realization of a thermal imaging confirms this degradation and the presence of cold spot at the junction outside wall / floor. The two zones are surrounded on the figure below.

Figure 3. Infrared thermography performed after the renovation

Figure 4 bellow shows one of the failure event graph developed from FMAE study. The analysis of this graph allows us to identify the consequences of these cold spots and water infiltration.

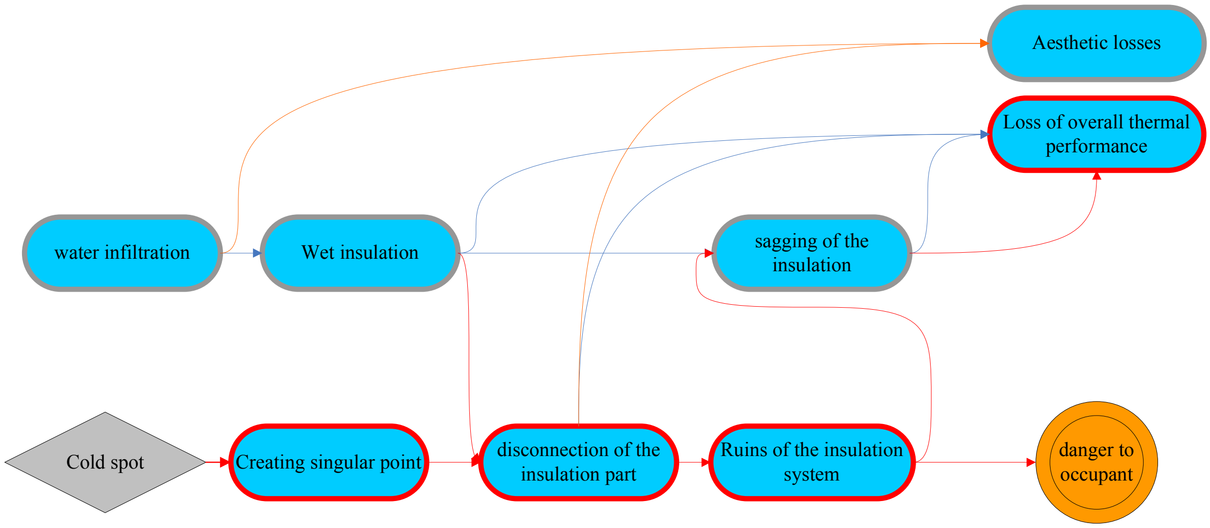

Figure 4. Failure event graph of deterioration of the External insulation renovation

We note that the consequences can be of 3 types:

- Aesthetic losses;
- Loss of thermal performance;
- Destruction of the structure and therefore potentially dangerous to people.

To be complete, the probability of occurrence of the different events has been taken into acount.Results shown that the ruin of the insulation system remains very unlikely. In contrast some water infiltration may create aesthetic losses without too serious consequences.

7 CONCLUSIONS

The proposed approach, through simplified FMEA allowed us to evaluate the consequences of a renovation on the expected functions of a building (transfer of moisture, thermal performance, indoor air quality, structural stability, occupant safety). Several potential failure modes related or caused by retrofiting have been identified.

FMEA at macroscopic scale is quite innovative and allows to reuse the work done to any building or building renovation and open the way to Risk analysis from component to building scale.
Furthermore, this approach may serve as decision helping tool for project owner involved in renovation projects.

To complete this study, it is still important to work to determine the occurrence and severity and thereby define an criticality assesment of the identified defects .

In addition, incorporation of a time scale in the degradation phenomena will also helps to identify priorities for action or further feasibility studies.

ACKNOWLEDGMENTS

This study has been supported by the ADEME (French Environment and Energy Management Agency)

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