Use of FMEA - failure modes effects analysis on moisture problems in buildings

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1. INTRODUCTION

The traditional method used for solving moisture failures, as a water leakage in a building is to make an investigation and find the cause and repair the leakage. This solves the problem now, but it does not always prevent future failures. We need a systematic method to avoid future moisture problems. Solving similar failure problems is important in many industries as in production of aircrafts, cars and computers. The producers want to prevent failures by analysing the systems before production and getting a feedback from accidents. This is well known in the airline industry, where every accident is analysed to find the cause and after each accident a number of changes in the design or in the maintenance is suggested.

The building sector is different from most stationary industry as only part of the building process is industrialized and the rest is done as craft. Many operations are not repeated and the work is adjusted on site. The workmanship is therefore important for the result. An analysis must include both technical and human errors.

We are interested in moisture problems in buildings, as we know that living in a "moist building" give a higher risk for health problems (Bornehaug et al. 2001). We do not know if it is emissions or mould or other factors that is problem. We have to look at too high moisture content (condensation and free water) as a problem. Finding methods to reduce the moisture failure modes will be economic both from a maintenance and indoor climate perspective.

2. MOISTURE CHECK LISTS

Today we try to prevent many of the moisture problems by using check lists with the points you have to think about, when you design a building. An example is found in Samuelson and Nielsen 2002. These lists have a tendency to be rather long and include both minor and major problems. There is no information of the consequence of not following the rules. Having a better understanding of the risk involved with the failures would make it more evident, when to use extra control and/or make a change in design to reduce costs of future failures.

3. FAILURE MODE AND EFFECT ANALYSIS (FMEA)

What is a failure? Failure is defined as the inability of any asset to do what its users want it to do. A failure mode and effect analysis (FMEA) as described in US MIL STD 1629 (1980) and Moubray (1999) are intended to recognize and evaluate the potential failures of a product (the house) or process (construction) and find its effects. It will identify actions that can be taken to prevent failures by eliminating or reducing the risk. The concept of FMEA is nothing new. Designers have always thought of failure modes and how to prevent them. In construction we have many rules and guides of how to build a house without future failures, but in most cases we do not look at the effect of the failure. The FMEA method uses a more systematic approach.

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There are two types of analysis. The first type is the design FMEA, where an evaluation is done at the design stage. At this stage it can be very helpful to identify possible failures and establish priorities based on severity and uncover oversight, misjudgements and errors that has been made. In the process many failures can be prevented before the house is build and also define where it is necessary to test or control the solutions. The second type is the "as build" FMEA where we look at a finished building and identify possible failure modes. This is in other applications called "Process FMEA" as most FMEA is made on production processes in the industry.

4. THE BUILDING AS A SYSTEM

The FMEA will typically begin with a number of block diagrams. The purpose is to understand the logic in the system. In traditional building physics we look at moisture problems in constructions and do not look at the water and heating installation. But to prevent damage from water systems it is important to go to the source and also look at the installations.

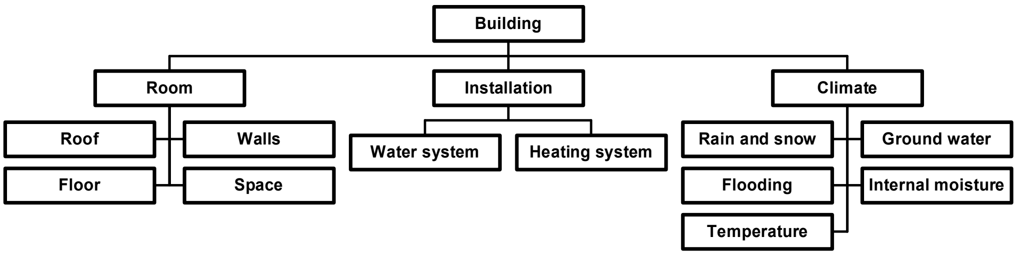

Figure 1. The building as a system

Figure 1 views the building as a system divided in three parts: the room, the installation and the climate. The room is divided in the different structural parts as roofs, walls, floors and the space (humid air). The installations are divided in water system for cold and warm water and the water based heating system. The climate includes the effect of rain and snow, flooding and ground water and internal moisture sources. The next phase is to subdivide the technical systems as for instance the water installation in figure 2.

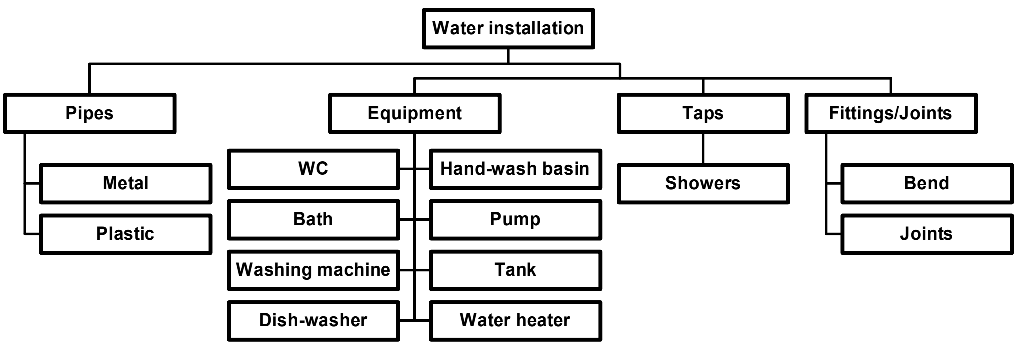

Figure 2. Water installation

On the top level we divide it in pipes, fittings, taps and equipment. Pipes are single length pipes without joints and fittings. All joints between pipes and between pipes and fittings or equipment are taken in a single group, as these are weak points with a higher risk. Taps are points with a high risk if left open. Showers are in the same group. The equipment group consists of all the different types of water-connected equipment.

Analysing a water installation as a separate system can be done in a FMEA analysis similar to many process systems in the industry. But the analysis cannot be done without information on the building, as a leakage will have different consequences depending on where it occurs. In rooms with drain the water can run out without making damage. The repair costs will be low. In rooms without drain as living rooms or worse in hidden spaces will a leakage give a more extensive damage and the repair cost can by high if a leakage is not stopped immediately.

We also need to analyse the room in the building in more detail. We can make a diagram as for the water installation that describes the parts as walls, roofs, floors and spaces. This can be further divided. An example is that the wall is divided into three parts – the outer, the inner surface and the central part. On the inner surface we can get running water or condensation – in both cases we are able to see it and make repairs. Inside the structure we can get interstitial condensation and high moisture content from water or condensation. The outer surface is only interesting, if the water moves into the structure. The difficulty in cases with water inside the structure is that moisture problems are hidden until we see it on the inner surface or we smell mould in the room. At that time the repair cost could be rather high.

The spaces or rooms can be divided in wet rooms and dry rooms. Wet rooms as bath, washing and boiler rooms have a high risk for water leakage and therefore must have a drain. Dry rooms as living rooms, sleeping rooms, kitchen, entrance halls and storage rooms are made without drain. A water leakage in these rooms can be expensive. Note that the kitchen is placed in this group, as there is normally no drain from the floor. But it is normal to make kitchen floors so that they are water resistant but not always watertight. Water drops or water spills can then happen without making damage.

5. FAILURE TYPES

Potential failure modes in industry are modes where the system fails totally or not being able to output the expected amount or quality. Moisture failure modes will include excess moisture in the building. Main failure modes in the top (1.level) can be divided in:

- Free water in the building - example leakage from water installations
- Surface condensation - example bathroom after bathing
- Internal condensation in the structure – roof without a vapour barrier

Table 1 shows part of a failure mode table for moisture problems in buildings. It includes failure modes from free water in the building (level 1). In the next level (level 2) we describe the causes that can give a level 1 problem. Two causes is described in more details rain water leakage and leakage from the drainage system. It is often thought that we can find “root causes” in the analysis. It implies that we can find a final and absolute level of causation. This is very seldom the case. We will generally be able to go in still more detail with the causes. In the table 1 we have stopped at level 5. The information is based on (Andersson and Kling 2000), (Nevander and Elmarson 1994), (Nielsen 2000) and (Norwegian Building Research Institute 2001). The total table of failures modes is 6 pages.

6. FAILURE EFFECTS

After the failure mode analysis we must find the failure effects - “What happens” when a failure mode occurs. The failure effect describe if obvious physical effects as unusual smell, visible moist spots or pools of water on the floor accompany the failure. Table 2 is a table with description of failure effects for some failure modes in table 1. After making a list of failure effects it is possible to write prevention methods for each failure as in the table. This could for instance be to make tests and check of the workmanship quality.

Table 1. Failure modes from liquid water in the building (level 1).

Level 2	Level 3	Level 4	Level 5
Leakage rain water	Leakage from roofs	Leakage in roofing material	Mechanical damage
			Montage error
			Aging of material
		Leakage from skylights	
		Leakage from roofing felt joints	Montage error
			Mechanical damage
			Aging of material
		Leakage from gutters	
		Leakage from joint to walls	
		Leakage from joints with pipes, cables and duct going through the roof	Montage error
			Design error
			Cracking from movements
Leakage from drain system	Leakage from pipes	Leakage from pipe material	Mechanical damage
			Corrosion
			Too high temperatures
			Constant water pressure
		Leakage from joints between pipes	Montage error
	Leakage from fitting	Montage error	
	Leakage from drains in floors	Montage error	
		Filled with solid waste	
	Leakage from watertight floors (ex. bathrooms)	Leakage trough material	
		Leakage trough joints	
		Leakage joints with walls	
		Leakage joint with pipes, cables and ducts	

The same failure effects from moisture in buildings can have different causes. An example is condensation seen on a surface; this could come from a thermal bridge, a low ventilation rate, and extra moisture in the indoor air from cooking, bathing and so on. Another example is failure effects from free water in the form of dripping or water flows. This could come from leakage in the water or drainage system, leakage in the heating system and drips from condensation on the surface or in the construction. In some cases is the source obvious as a leakage from a dishwasher. In other cases is the source hidden and it is not possible to find the failure mode without having drawings and/or opening of the construction.

Table 2. Failure modes, failure effects and prevention methods for leakage in roofs.

	Failure modes	Failure effect	Prevention method
Leakage in roofing material	Mechanical damage	Seen as dripping or water flow in the building during and after rain. Location of damage can be very difficult.	No normal traffic on the roofing material. Remove all waste material on roofs. Inspect roof.
	Montage error	The roof leaks shortly after construction. Seen as dripping or water flow in the building during and after rain. Location of damage can be very difficult.	Control system for workmanship. The contactor must repair the damage.
	Aging of material	The material cracks from frost damage or temperature variation.	Use materials tested for aging in a climate as on site. Inspect roof and look for cracks or other damages
Leakage from skylights		Seen as dripping or water flowing in the building at the skylights during and after rain.	Use skylights that have been tested for water tightness. Have control system for workman-ship.
Leakage from roofing felt joints	Montage error	The roof leaks shortly after construction. Seen as dripping or water flow in the building during and after rain. Location of damage can be very difficult.	Control system for workmanship. The contactor must repair the damage.
	Mechanical damage	See mechanical damage on roofs	
	Aging joints	See aging of roof materials	
Leakage from gutters		Water damage on facade from gutter leakage. Possible water damage into constructions.	Control gutters for leakage. In case of repeated leakage should gutters be repaired.
Leakage from joint to walls		The roof leaks. Seen as dripping or water flow in the building during and after rain. Location of damage can be very difficult.	Roofing material should continue approx 10 cm up connecting walls. Rain should not be able to come under the roof material at the joint.
Leakage from joints with pipes, cables and duct in the roof	Montage error	The roof leaks shortly after construction. Seen as dripping or water flow in the building during and after rain. Location of damage can be very difficult.	Montage of signboards or ventilation equipment on the roof must be specially checked to ensure watertight solutions
	Design error	As above	Areas around pipes, cables and duct must be planned, so it is easy to make watertight solutions.
	Cracking/ Movements	As above	Look for cracking around pipes, cables and ducts.

2. FAILURE PATTERNS AND RISK EVALUATION

We have an intuitive expectation, that the failure rate is low for new things and it is will increase with time. This is incorrect in many practical cases. The classical failure pattern is called the bathtub from the drawing of the risk. There is a high-risk of for instance a water leakage in the start and the end. In between the risk is lower. The infant mortality in the start is caused by: poor design, poor quality manufacture, incorrect installation, incorrect operation, unnecessary maintenance and bad workmanship. We know that infant mortality is a problem for many systems as many parts are made or installed on site. An example is water based heating systems. They have a high risk in the start from incorrect installation. Then the risk goes down. In the end it will increase from wear out from for instance corrosion. Other systems will have no infant mortality but a failure risk that will increase with time.

The FMEA analysis can be expanded with a risk evaluation looking at probability for loss of function, but this is difficult for buildings, as we do not collect systematic information on the failure risks from different constructions. Calculation of risk can sometimes be done as for condensation in a wall (Nielsen 1995). In most cases we can intuitively state that certain solutions are more risky than another as placing a water tap in a room without drain. A complication is that the many failure effects are time-dependent.

Information from the Norwegian Building Research Institute (2001) shows, that around 80% of all investigated building failures is related to water and moisture. 70% of the moisture failures are related to water leakage and moisture transport, 20% is condensation and 10% is moisture from the building phase. The Danish Building Research Institute (Valbjørn and Eriksen 2001) has made an enquiry to professionals in the building sector about the risk for moisture damage in buildings. The participants were asked to mark the risk level as a point on a line going from little risk to high risk for each type of construction. Some of the results were:

- Installations presented a comparatively great risk of water damage.
- Pitched roofs without dormers or valleys run less risk of water damage than flat roofs or other types of roof with dormers and valleys.

3. USE OF FMEA ON ACTUAL BUILDINGS

The description until this point is in general terms. For practical use of the method we must make the analysis on an actual buildings. This is done with the following procedure:

Get the drawings of the building, the drawings of the water, heating and wastewater installation and the description of the solutions. In an existing building an inspection (make notes and take pictures) is necessary to check if the drawings describe the as build case. Traditionally in building physics we look at the different constructions as floors, walls and roofs. In this case we are also interested in getting a good indoor environment without moisture problems and will start looking at the rooms.

Make a list of all possible moisture sources in each room. First include internal water installation, water-heating installation, drain system, periods with high moisture content in air (from bathing, cooking and so on). Second include moisture from rain and snow, surface water and ground water.

Then start by looking at the water installation – where is high-risk points, taps, fitting and so on. Each point is giving a risk value from 0 to 10. These values are then reduced if the room has a drain and a watertight floor or other risk reducing methods is used. An example is a disk washing machine that will have a risk of 10. If we place it on a watertight floor with drain the risk is reduced to 3. The risk can still be reduced, if we always close the water tap after each used or we use a break preventer valve, which will stop the water flow if the tube between the tap and the machine breaks. A list of risk values will be found in the final description of the method. The result is risk values for each room and a value for the whole building. Similar methods must be used for all other moisture sources. In looking on the possible causes we use our FMEA analysis as a basis and supplement with cases that is not covered in the general list. Make a total risk value for each room in the building. The risk values give the possibility to compare different solutions.

In the design phase we can specially look at rooms with high risk values and try to reduce the risk values by changing the construction and installation. Some of these reductions can also come from a better quality control of the work. In that case it is important that this information is given the workmen at the site. For the finished building we can see where we have risk points, and that is where we should check in the operation phase.

The method described here can also be done existing buildings. The analysis of an existing building should be done with the people responsible for the maintenance as they known previous moisture problems in the building. The result of an analysis of an existing building is to help in the maintenance and give a better understanding of where future problem could come.

A problem with the method is to give risk values 0-10 to different failure types and reductions for prevention methods. Making the list should be done by a group of people with experience from practical moisture problems including maintenance people.

A more comprehensive report with examples of the methods use will come from the project.

4. CONCLUSIONS

A FMEA analysis is a good help in finding better solution for moisture proof buildings. Using this systematic approach gives better understanding of building failures, their effects and remediation methods. Finding and preventing hidden failures is a very important task. Using the right solution in the constructions can also reduce the risk of serious damage from water leakage. The analysis is important in the building phase but must include the influence of the user and the lifetime of the building.

The analysis is also very useful in facility management (FM). The building owner will have an interest in the keeping the running cost down and still get a good indoor climate. The management of the building can collect very much information on the cost and types of failures during the life cycle.

The user can increase the risk of moisture problems in the building. The behaviour can give a much higher risk of problems without the user knows that this is the case. Making information for the user is a very good idea that can save money in the management of the building.

FMEA analysis on buildings is a method for better quality of the buildings, as results from research and practise is combined. The analysis results as checklists and information on critical points should be structured for the different parties in the building process as architects, engineers and craftsmen. Selecting, building and keeping moisture-proof constructions are important for preventing health problems in buildings.

5. ACKNOWLEDGEMENTS

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