Reducing the risk of future moisture problems in buildings

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ABSTRACT
Dampness in buildings is a health risk that can be reduced by preventing moisture problems. A Swedish investigation of water damage in existing buildings shows that the typical cost of a damage is 3500€. Another investigation shows that the cost of repairing failures in the building phase is around 100€. It is therefore economical to prevent failures in the building phase and make sure that they can be found in an early stage. To reduce the risk we must identify risk points and know how to prevent failures and find the effects of leakages. The Failure Modes and Effects Analysis (FMEA) and Reliability-Centred Maintenance (RCM) methods are used in other industries. This are suggested to be used on installations in buildings in the design, building and maintenance phases.

INDEX TERMS
Moisture; Water damage; Failure modes; Maintenance; Costs; Technical installations; Building construction

INTRODUCTION
'Dampness' in buildings gives a higher risk for health problems (Bornehaug *et al.*, 2001), than dry buildings. For this reason, it is important to reduce the risk of moisture damage in buildings. As we do not know the coupling between moisture and health we must regard excess moisture as a problem. Investigation of moisture damages in the building phase shows that it is cheaper to rectify them at that stage. Water damage in existing buildings is much more expensive to repair. We need a systematic method to avoid future moisture failures. Solving similar failure problems is important in many types of stationary industry as production of aircrafts, cars and computers. The producers want to prevent failures by analysing the systems before production and having a feedback from accidents. This is done in the aviation industry, where every accident is analysed to find the causes. After each accident, a number of changes in the design or in the maintenance are suggested. The failure modes and effect analysis (FMEA) method can also be employed in the building sector. This paper will present examples of failure modes and what can be done in practice to prevent it in the design, building and maintenance phases.

FAILURES IN THE BUILDING PHASE
A Swedish investigation (Josephson and Hammarlund, 1996) of building failures at seven building sites during erection has collected failure types and their costs. It includes only mistakes done during the building phase and repaired at that time. It was found that the failure cost was 4.4% of the total production costs. Here we will only look at building failures related to water and moisture. This is only 5% of the total number of failures and constitutes a lower percentage based on the costs. The moisture failures have been divided into six groups, as seen in Table 1.

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Table 1 Damages from moisture and water in the building phase

	Number	%	Average cost (€)	%
Rain and excess moisture—includes cost of drying out of structures	23	19	570	32
Installation leaks—water and heating systems	31	25	65	5
Wet rooms such as bath and WC	20	16	410	20
Drain pipes—many in wrong position	9	7	450	10
Roof construction leaks	21	17	410	21
Wall construction leaks	19	15	280	13

Most failures are from work that is not done in accordance with the description and drawings. Few of the repaired failures can be classified as points that can prevent future moisture problems in the finished building. This is probably caused by little or no feedback from the maintenance people to the building process. Another serious problem is that avoiding rain and water damage does not appear to have a high priority in the building phase.

The average cost of a damage is 3–600€ with a few expensive failures and many inexpensive ones. For example, the cost of putting in a missing floor drain is around 100€, whereas a mistake in mounting the drain costs much less. If this is not done correctly or has not been found during the building phase, the repair cost can be much higher, especially if a leakage occurs later. It is also a problem that the general guarantee time for buildings in Sweden is only 2 years and many failures are first detected much later—only some buildings have a 10-year insurance against building failures.

WATER DAMAGE IN BUILDINGS

A new study of water damages in Swedish buildings (Vattenskador i byggnader, 2002) contains information on failures that have been reported to the insurance companies. The insurance covers only events that happen suddenly and this is only part of real water damages. The study gives a nationwide documentation for the causes of water damage in buildings in Sweden and the following tables are from this investigation. The total repair cost of water damage in buildings is estimated to be more than 600 million euros per year.

The aim of the study is to produce a detailed set of statistics and data on the underlying causes of water damage. Table 2 gives the main areas for water damage and their costs. The main area of concern, both in number and in economic terms, is piping. The average cost is 3–4000€ for a damage.

Table 2 Main fields for water damage in buildings

	Number	%	Average cost (€)	%
Piping	4413	60	3900	68
Appliances	987	13	2700	10
Wet room sealed surfaces	1982	27	2900	22

We will only look more in detail at the first two groups. The piping system had most damages as seen in Table 2. The damages can be sorted on the type of water system as in Table 3. The cold water system and the heating system have the most damages.

Table 4 gives the technical causes of the damages in the piping system. Corrosion and freezing are the most common causes of leaks from piping systems. In this study, it was found that frozen pipes accounted for 20% of total water damage and were thus the largest single cause of water damage. This high percentage is a consequence of the cold winter climate in Sweden.

Table 3 Piping systems, where the damage occurs

	Number	%	Average cost (€)	%
Cold water	1649	41	4700	49
Warm water	364	9	4600	11
Heating	993	24	2700	16
Water-based floor heating	29	1	3600	1
Drain	1029	25	3500	23

Table 4 Technical causes for failures in the piping system

	Number	%	Average cost €	%
Corrosion	1502	34	4700	26
Mechanical damage	325	7	4600	6
Human factor	245	6	2700	5
Freezing	788	18	3600	29
Other	1553	35	3500	34

We will now look at the appliances. Dishwashers are found to be the most frequent source of water damage as seen in Table 5. The same was found in a previous study from 1987, which means that the water damage safety in dishwashers has not improved. In the cases where breakaway valves were mounted on hook-up hoses to the dishwasher, they have not worked in the intended manner. The study shows that damage caused by leaks from hot water heaters has a higher average cost than damage caused by other equipment. Many water heaters and dishwashers in Sweden are placed in rooms without drain.

Table 5 Appliances that gives water damage

	Number	%	Average cost (€)	%
Dish washing machine	454	46	2600	49
Washing machine	39	4	2900	11
Warm water heater	178	18	3344	16
Cool/freezer	89	9	1600	1
Other	237	24	3000	23

FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

The results from the two Swedish investigations show that it is economical to make an analysis of failure modes and their effects before the building is erected. A more detailed description of the FMEA method is found in Nielsen (2002) and an example of the use on a bathroom in Nielsen (2000). Here, we will look on an analysis for leakage from water systems (Table 6). The table does not include all possible failure modes—but selected examples for water systems as described in the first two columns. Failure effects describe, 'What happens' when a failure mode occurs. The failure effect description shall state if obvious physical effects accompany the failure, such as visible moist spots or pools of water on the floor. The same failure effect can have different causes as finding liquid water in the form of dripping or water flow. This could come from leakage in the water or drainage system, leakage in the heating system and drips from condensation. In some cases the source is obvious, such as a leakage from a dishwasher but this is not always true. After making a list of failure modes and effects it is possible to write prevention methods for each failure as it is done in the table. This could, for instance, be to make tests of the system and check of the workmanship quality.

Table 6 Leakage from water system

Level 4	Failure modes	Failure effect	Prevention method
Mechanical damage of pipe	(1) Sawing or drilling in water pipe	Instant water leakage seen by person sawing or drilling, if the system is under normal water pressure	No drilling or sawing without a drawing of the water system or using a metal detector to find pipes (not for plastic pipes)
	(2) Break of water pipe material from pressure and/or temperature	Sudden water leakage not seen by occupants or seen after freezing periods when thawing	Control the maximal pressure and temperature in the system—have meters; insulate pipes
Corrosion of pipe	(3) Corrosion of water pipe from water type	Starts as dripping after a time; not seen before leakage	Get information on the type of water you will have; keep pipes in room with drain; look after drip and repair if found
	(4) Wrong material in water pipe	Starts as dripping after a time; not seen before leakage.	Select materials that do not corrode if used together; keep pipes in room with drain; look after drip and repair if found
Leakage between fitting and pipe	(5) Assembly error—no sealing or not watertight	Small or large water leakage found when the water system is pressurized first time	Good workmanship; pressurize before internal materials are mounted, so the damage is less and easier to see
	(6) Sealing leaks —long term	Dripping from sealing; worst in rooms without drain	Good workmanship
Leakage in fitting	As leakage from pipes	See pipes	
Internal leakage in the machine	(7)	Leakage from washing and dishwashing machines seen as dripping and water below after use	Place the machines in rooms with drain; check the floor after use for leakage; if leakage, call repair service
Leakage from tube between tap and equipment	(8)	Leakage from water tube to washing and dishwashing machines seen as dripping and water below after use	Place the machines in rooms with drain; check the floor after use for leakage; If leakage found, change tube

DESIGN AND BUILDING PHASE

A study by Josephson and Hammarlund (1996) shows that many building failures during the erection are caused by errors in the description, drawings or during the building process. From

Table 6 one can see that most problems need to be solved during the design phase or during the work on site. Quality control is very important, but explanation is required as to why something must be done in a certain way. An example of a successful method is the Vaska project (Andersson and Kling, 2000), where the number of failures in a 10-year period was very few and much lower than in other building projects from the same period. The method is well documented but not used in most Swedish buildings; perhaps it is difficult to change the normal practice.

MAINTENANCE

Having information on the failure effects we can take a look at the maintenance phase. Can we prevent failures or make early detection? Reliability centred maintenance (RCM) is a technique (Moubray, 1999) for determining the preventive maintenance and need for inspection of physical assets. It originally came from the aviation industry in the 1970s. After that it has been used in many other types of industries. In the aviation industry it has reduced the number of failures and made flying safer. When the technique is used on new buildings it will—in the design and building phase—help to select solutions that reduce the risk and find the maintenance and control needed in the final building. The RCM has seven basic questions:

- What are the functions of the asset in its present operation context?
- What functional failures can it suffer from?
- What failure modes can cause each functional failure?
- What are the effects of each functional failure and failure mode?
- What would be the consequences of each functional failure, if nothing were done to prevent it?
- Can maintenance or inspection tasks be performed to prevent or predict the failure?
- What should be done if no maintenance and inspection tasks are useful?

The first four questions are solved in the FMEA analysis. The next question on the consequences of each failure can be described technically. But we need economic data to show that new solutions are cheaper for the lifespan of the building. The economic consequences are not easy to find in the building industry. For water damages, the Swedish investigation can tell us which failure types are most expensive and which occur more often.

Some failures are easy to spot and obvious to find, for instance, a leak in a dishwasher. It is much more difficult to ascertain the cause if water is seen dripping from a wall. Is it a leak in a pipe or is it because of rain or condensation? This is a typical hidden failure where we have to use failure-finding techniques to determine the real failure mode. If we look at failures found in the failure mode analysis in Table 6 we will see that many failures are hidden, so the operator cannot know the cause before making a failure finding. It is important that the system has easy access to inspection and location of water failures. This reduces the problems with hidden failures.

For the causes in Table 6 we can see that all the point must be supervised in the building process. We need to include these points in our quality control system at the building site and also define who is responsible for the control.

When the building is finished, we go into the maintenance phase. In this phase, we still need our analysis but not all points are important. For drilling (point 1—numbers see Table 6 column ‘Failure modes’) in the building it is important to know where the pipes are—keep the drawings updated. The pressure in the system must be checked (point 2). In points 3 and 4 we must look at possible drips, but this is difficult as it is probably not economical to make routine inspections. In flats, it is best to get the inhabitants to react, if they see dripping. They will probably see it first. For points 7 and 8 it is again the inhabitants who will see the problem first, but it is a good idea to place water systems in rooms with drain. From these examples, we find that in the building sector it is not normally economical to make routine inspections. But it is important keep a list of all repairs to see if the number is increasing. In that case, inspections and renovation can be economical. Keep records of failure finding tasks. Do the function works every time? How often does the function fail?

Condition monitoring is a method for finding the condition of an appliance/equipment with another instrument. An example is to look at the water flow during the night to see if it is zero. Primary effect monitoring is reading of instrument that can indicate if the system is working normally. An example is a pressure gauge to see if the pressure is in the correct range. These examples should be included in the maintenance.

CONCLUSION

Preventing moisture problems and water damage in building must combine the information we have from different sources. This can be done with the FMEA analysis on buildings and systems. The method can give better quality of the buildings, as the analysis combines results from research and practice. The analysis is important in finding better solutions for moisture-proof buildings. Using this systematic approach gives a better understanding of building failures, their effects and remediation methods. Finding and preventing hidden failures is a very important task. The important points are found in all part of the building process—in the design, building and maintenance phases.

- In the design phase it is important to place the piping so it is easy to inspect and locate a leakage. An example is to have floor drain in all rooms with appliances such as dishwashers, water heaters and water taps. This must be checked in the design phase and it should also be possible to compare different solutions and estimate the risk levels.
- In the building phase it is important to have a quality control system that guarantees that the work is done as designed and the workmanship does not give new problems. Areas with problems are typically water tightness at the floor drains, pipe connections and connections between pipes and appliances.
- In the maintenance phase is it important to find leakages at an early stage. Information to users should be on how to see failures and what to do. It is in most cases not practical to make regular inspections of the technical systems in, for instance, a block of flats, but an inspection should be done when the tenants move out and new ones move in. For the facility managers it is important to collect data of moisture failures as an increasing number of cases are a sign that the life-span of, for instance, the piping is over. In these cases, a renovation should be done.

Selecting, building and maintaining moisture-proof constructions and installations are important for preventing future health problems for the building's inhabitants. A more extensive description of the methods will be published later this year.

ACKNOWLEDGMENT

The work is supported by FORMAS—the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning.

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