Use of Dehumidification to Reduce Preventive and Corrective Maintenance of Aircraft Due to Corrosion

Ltc (Lt Col) – retired Håkan Schweitz
Competence Centre for Logistics
Swedish Defence Material Administration
FMV, Box 1165
SE-581 11 Linköping
SWEDEN

hakan.schweitz@fmv.se

1.0 INTRODUCTION

As a background to dehumidification of aircrafts in use, I will first give you information about our earlier experiences which got the Defence to start with tests and developing of dehumidification of materiel in use.

The Swedish army has used the dry air technique since 1958. Until 1984 only for materiel in depots (mobilization storage). The aim was that all materiel could be stored during four years without any maintenance inspections or measures. For all materiel which contains electronic components it was necessary to use dehumidification.

The reason why the materiel should be stored during four years, was that the military units, such us parts of a brigade make refresher courses every fourth years.

In Sweden we use some different ways for store the materiel in a dry air environment such as:

- Dehumidification of the entire storage building.
- Dehumidification of some part of a building – “dry air box”.
- In a plastic bag.
- By a duct system from a dehumidifier let dry air inside a vehicle or into a staff cabin.

2.0 INVESTIGATION ON MATERIEL IN MOBILIZATION STORAGE

In Sweden we have done comprehensive investigations of the materiel in mobilization storages. The aim of the investigations was to see how storage affected the materiel over longer periods of time. With the experiences we got, we now have the possibility to recommend the best choice of material when we developing new equipment, in order to keep a high availability and low costs. Between 1972 and 1986 we made comprehensive measurements of the environment by continuously measuring following subjects on three places in the country:

- Relative humidity.
- Sulphur oxide.
- Hydrosulphuric acid.
- Nitrogen dioxide.

- Ozone.
- Intensity of the sun.
- Gliding ashes.
- Falling ashes.
- Direction of the wind.

We stored the materiel in 4 different environments:

- Outdoor.
- On an open shelf in the storage.
- In a dry air box.
- In a dry air box with filtered air.

Following materiel have been investigated:

- Tanks.
- Cross country trucks.
- Radio transmitters.
- Spare parts.
- Packing of rubber and plastic.
- Textiles.
- Medical articles.

Following material are followed up:

- Sheet of steel, unprepared and zincified.
- Sheet of aluminium, unprepared.
- Sheet of silver, unprepared.
- Sheet of copper, unprepared.
- Rubber, 14 different kinds.
- Plastic, 7 different kinds.

We made these investigations in cooperation with Swedish industries.

3.0 EXPERIENCES FROM THE STORAGE TEST PROJECT

3.1 Components Showing Some Changes

3.1.1 Rubber Details

It is important to choose the right quality of rubber when new equipment is purchased. If one looks at price and quality from a short term angle, when the material is new, this may lead to expensive repairs and

equipment with low readiness in the future. One has to consider how sensitive the materiel is from an environmental point of view.

- More or less important changes of quality have taken place in the exposed specimens outdoors and inside storage-rooms with untreated air.
- Rubber, i.e., tyre-rubber, were seriously attacked outdoors as well as in a storage-room with non treated air. In other environments however, attacks have not been observed.

From the results you can draw the conclusion that a storage-environment of dry air of 50 % is favourable to all the tested qualities of rubber.

3.1.2 Plastic Material

A number of plastic bars have been part of the test. Only polypropene showed a lower tensile strength in all environments while other plastics passed without any remarks.

3.1.3 Printed Circuit Cards and Contact Instruments

On printed circuit cards no significant changes due to different storage conditions have been observed.

3.2 Components Showing Little or No Change

After eight years of storage the following components show no or slight changes.

3.2.1 Condensers

The attacks of corrosion on the metal-enclosed condensers were the most serious outdoors.

The test result shows that no alarming interruptions have occurred. However, when using condensers in equipment attacked by corrosion and exposed to mechanical strain, such as from vibrations or outdoors environment, it is to be feared that this corrosion might cause a break on some connection.

3.2.2 Packings

Nitrile rubber is the most common material when it comes to different kinds of packings. Research has shown that, in short time, nitrile rubber is affected by the ozone of the atmosphere.

The material that showed the best result after storage was fluorinerubber.

3.3 Conclusion of Storage Tests

The dehumidification technique gives:

- Long term storage with high preparedness.
- Limited maintenance activities during storage.

4.0 DEHUMIDIFICATION OF AIRPLANES IN DUTY

FMV started 1980 a test activity aiming at an examination whether the dry air improves the environment within the aircraft to such an extent that the number of failures of instruments and components will decrease

in the different systems. An improvement of the environment should, except for decreased maintenance costs, also mean increased reliability and availability. The corrosion attacks on the engine as well as on other parts of the aircraft were also assumed to decrease.

23 airplanes were used as reference group and 10 were connected to dry air as soon as they have finished their daily flights. These planes have been connected with dry air, when placed in hangars. The airplanes in both groups was chosen at random. The dry air have been provided with dry air both through one air intake to the engine and through ground connections for cold air in the rear instrument space to radar and wing electronics. Air has punched through into the cabin and through the outlet valve also to the front apparatus room. Measurements of the distribution of the dry air within the airplanes were carried out. These measurements show that dry air pushes through to several other spaces than anticipated and this causes a much drier environment for other instruments within the airplane.

In Figure 1 you can see the Relative Humidity at several places in the aircraft. In the reference aircrafts the values of RH were over the critical limit - 50% is where you will start to get problem in the electronic equipment. By our follow-up system and information from services in the workshops, we got knowledge of all failures for an individual airplane so we could compare with its number of failures during the latest three years.

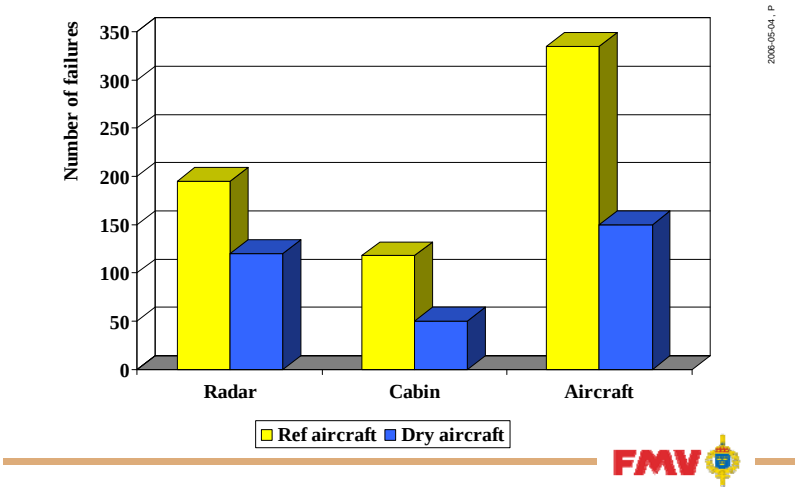


Figure 1: Effect of dehumidification on the number of failures in 2,300 flying hours.

In Figure 2 you can see values for calculation of MTBF; remember that it was 10 dehumidified airplanes and 23 reference airplanes. Because of that, the number are higher for the reference aircrafts. The graph shows that the MTBF values are much better for the dry air aircrafts. If you compare MTBF you can see that MTBF have increased much. If you do a calculation of failures at 2.300 flying hours - it was the flying time for the reference aircrafts, the difference is very high. For the entire aircrafts the MTBF- improvement increased with 26 %. The security will thus be improved by 26 % meaning that the availability will increase by 5 % in absolute figures. On an average this means that further one aircraft can be “put on the line”, based on a 20 planes/division.

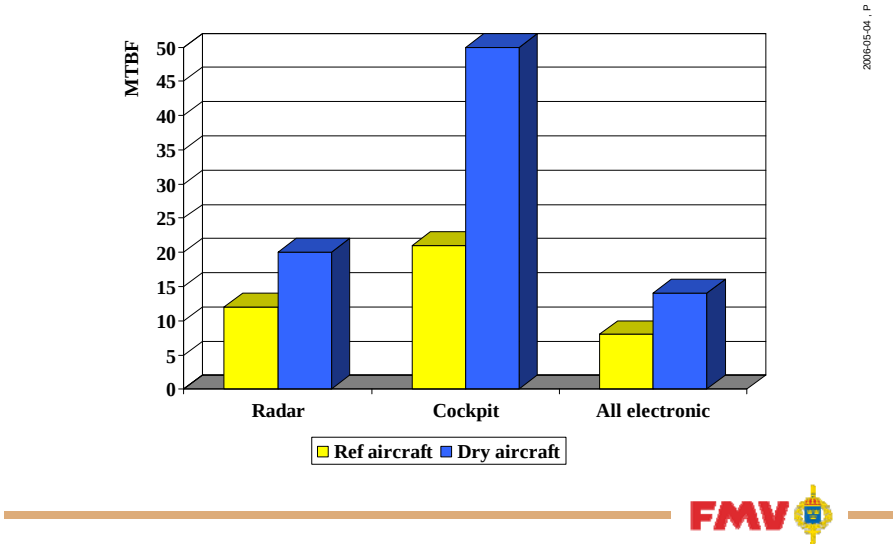


Figure 2: Effect of dehumidification on MTBF.

In order to be sure that the earlier mentioned improvements have not been caused by other factors, e.g., modifications with positive effect on the MTBF-values, both groups of aircrafts have been compared to each other during three years. This comparison shows that the reference aircrafts have deteriorated somewhat each year. The dry aircrafts show the same result during the first two years - before the dehumidification test - while an improvement can be seen during the last year.

The total number of failures have also been calculated for the entire aircraft giving 787 failures for dry air planes and 991 for reference planes at 2.300 flying hours. 156 failures can be referred to as improvements in radar and cabin instruments, while 48 failures can be referred to other systems.

If you look at the maintenance costs, these give a yearly saving of 100.000 US dollar in the monetary value of today at 2.300 flying hours.

As mentioned earlier it was not possible to judge decreased corrosion damages on engines during the test period, because the test period were to short, but we know now, after using the dry air technique even in engines, that we have got positive effects on aircrafts in duty.

Heated hangars might not be needed when no other activity is required in those facilities and thus certain hangars can be used only to stable “fresh airplanes” if they have been provided with dry air.

The installation costs per division are calculated to 80,000 US dollar and the operating costs to 4,000 US dollar per year. In addition, certain equipment, as for instance special covers and connections at 5,000 US dollar per division, might be required. Summarizing, it shows that the cost for installation and equipment can be saved already after about half a year!

The financial savings are as you can see rather great. This might not, however, be the most important thing, but an increased reliability and availability is probably the strongest argument for dehumidification of airplanes in duty! Now most of the airplanes and helicopters in duty are dehumidified in the Swedish defence. We are just working with a dehumidification system for the new fighting aircraft – Gripen.

Modern aircrafts have a lot of electronic equipment and other high tech materiel. These are very sensitive for humidity, pressure, changes of temperature. To protect the aircrafts you have to dehumidify them. FMV has developed a system for dehumidification which we can use during peace keeping operations. It means that each aircraft has its own dehumidifier (Figure 3).

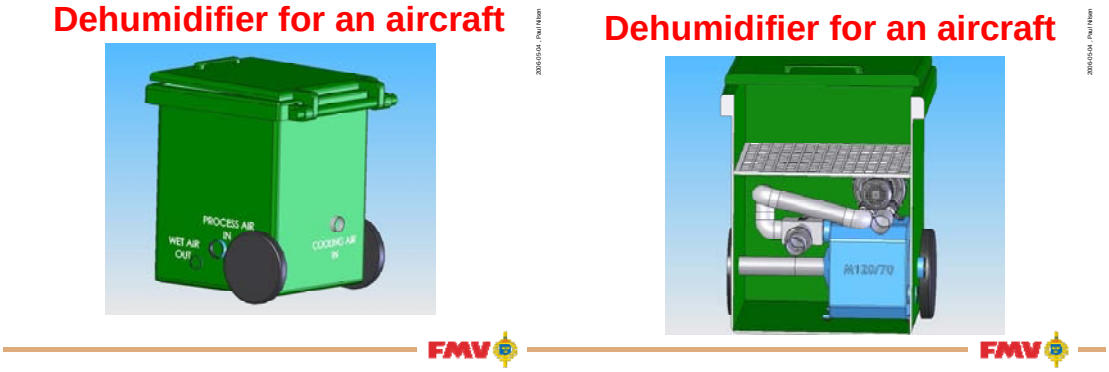


Figure 3: A dehumidifier for aircraft.

The aircrafts have also a system, which you call On Board Oxygen Generator. This have a material, which are very sensitive for humidity. Until now you have not had a good system to dry these units. FMV have developed a method, so you can dry them in the aircrafts, which save a lot of time and costs (Figure 4).

Figure 4: Dehumidification of the On-Board Oxygen Generator System (OBOGS).

The Air Force will use this equipment on special maintenance places for international missions (Figure 5).

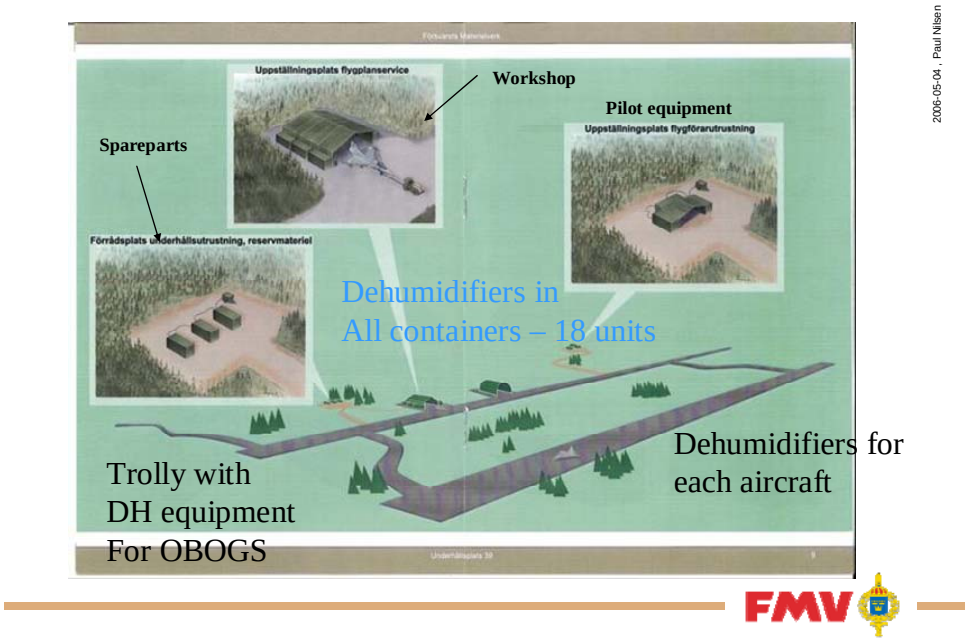


Figure 5: Maintenance during international missions.

We also use dry air in this Hercules cargo airplane. Tests showed that we very fast got a good dry environment in airplane. MTBF increased. As mentioned earlier, the avionics reliability increased, but we got also an environment in the cargo area, which prevent corrosion in the cargo.

FMV is also studying an application for dehumidification of an aircraft during flying. A Swedish company – CTT – has developed a dehumidification system which dry the ground of the aircraft and between the skin and the insulation (Figure 6). The system reduces the amount of water, which reduces the fuel costs, but more important is that it also reduces the maintenance costs. CTT install this system in all the new Airbus A380 and Boeing Dreamliner.

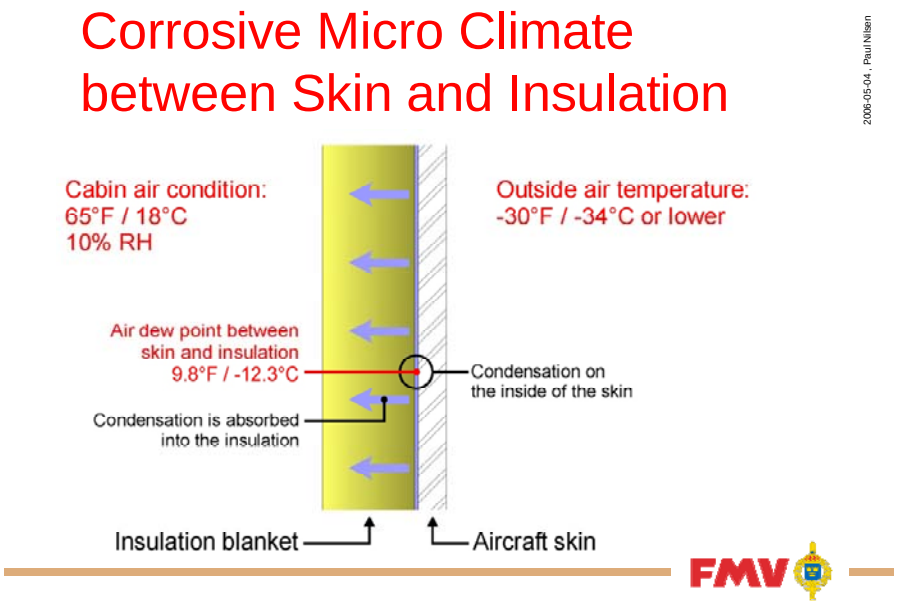


Figure 6: Condensation absorbed by the insulation blankets on the interior surface of an aircraft skin.

Appendix: Copy of Swedish Defence Forces Brochure on Dehumidification

DRY AIR – has saved tens of millions for the Armed Forces since the sixties!

The Swedish defence has been using dehumidification, commonly known as dry air, since 1958. But until the 1980s it has only been used for long-term storage of equipment. Thanks to good results obtained with dry air during storage, it started to be used as well for equipment in use for training purposes, etc.

Until the 1990s, Sweden had thousands of mobilisation depots spread throughout the country. These were often barns that the armed forces rented. As these depots were often situated far from the regiments, it was necessary to construct a maintenance system so that it wasn't necessary to visit the depots as often.

To begin with, the objective was to store equipment in the mobilisation depots for 4 years without any maintenance being carried out. There was also another reason for this period between maintenance occasions. Before, soldiers went on refresher training every four years and then often used the equipment that had been stored in "their own" mobilisation depots. This meant that the 4-year inspection of the mobilisation depot wasn't required.

In the mid-fifties, Carl Munter, a world-famous Swedish inventor, started to construct a dehumidifier.

(Carl Munter and Baltzar von Platen also invented the refrigerator, a product on which the Electrolux company was founded.)

FMV – then called the Royal Army Administration or KATF – was early to take part in the development of the dehumidifier as they considered it to be important technology in modern storage methods. In this way, the Swedish Armed Forces became Carl Munter's first customer.

There are many negative factors in our environment that must be taken into consideration when storing equipment.

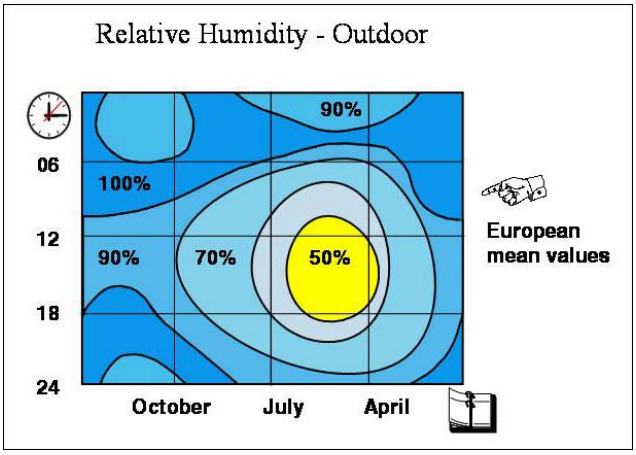
Surface deposits on equipment – increased risk of corrosion

- Metallic powder wear material in engines and gearboxes
- Sand from roads and terrain
- Old lubricant engine oil
- Grease old gun grease
- Salt seawater, agricultural land, sweat
- Acids forest, agriculture

Damp – water and water vapour

- Corrosion
- Impaired properties of some explosive substances

The important term to know is Relative Humidity (RH), which is the ratio between the amount of water vapour in the air at a certain temperature and the maximum amount the air can contain (%RH).



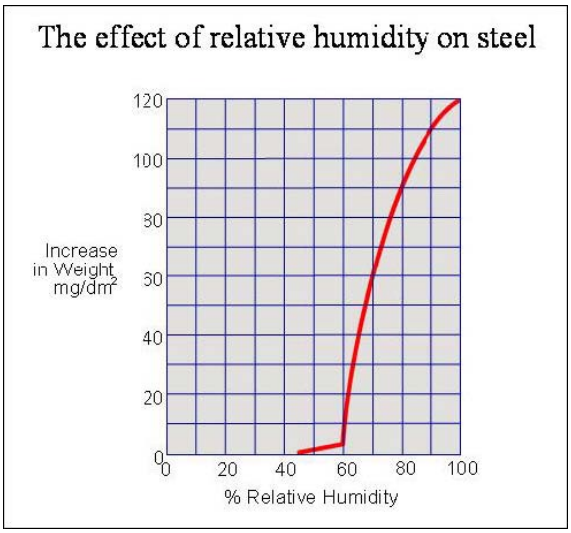
The figure shows that Relative Humidity (RH) is below 50% only for a few hours around midday in May and June.

RH is higher than 80% during most of the day and night. These values are the same in almost all of Europe.

As temperatures change between night and day condensation will form, which increases the risk of corrosion.

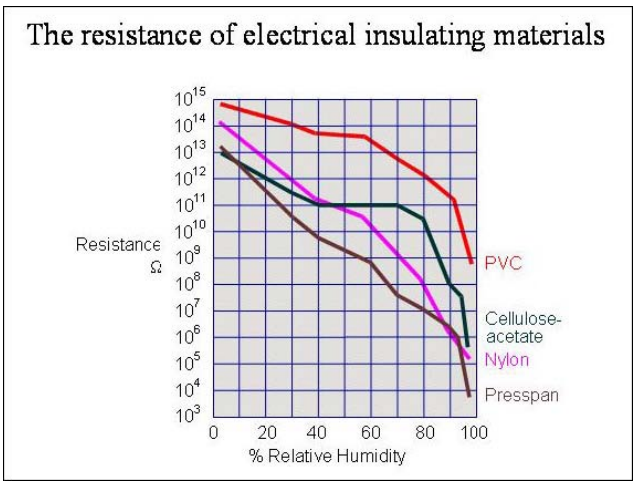
This variation is even greater in warm countries, making it even more important to dehumidify equipment when the Swedish Armed Forces are on international assignments, such as in Kosovo, Afghanistan, the Congo and Liberia!

Steel will start to corrode -- rust -- when the relative humidity is higher than 50%.



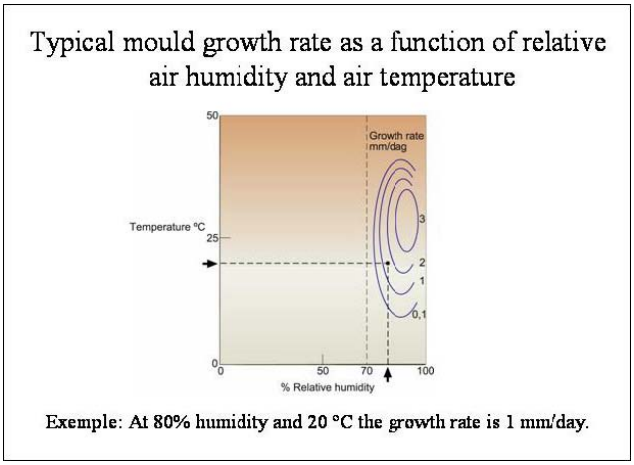
Other metals start to corrode at slightly higher relative humidity but still far below 80% RH.

Electronic equipment contains insulation, which is often sensitive to moisture. If the relative humidity is above 50%, its insulating properties will be impaired and consequently also the function of the electronic equipment.



Mould is a problem for both people and equipment. Mould starts to form at about 70% RH and is accompanied by severe health risks, which is why it is extremely important to minimise the risk of mould. Once mould has got a grip on the equipment, it is very expensive to clean.

Leather and fabric are often susceptible to mould. Mould can also separate grease, making it unusable.



Hot and cold

Temperature variations increase the risk of corrosion.

Partly, this may be due to rapid variations, hot nights and cold days for example, giving condensation resulting in problems with moisture as described earlier. This is a problem that arises especially when the Armed Forces are on peacekeeping duty in hot countries. Temperatures in the desert can be up to 40° during the day and only a few degrees above freezing at night.

Temperature variations can also be slower. After a long cold winter, the temperature of the steel in an armoured car or a container will be much lower than the surrounding air until late into the spring. This causes condensation both inside the armoured car and outside it that can subsequently cause damage to the electronics.

Ammunition is also very sensitive to high humidity and rapid variations in temperature. There is a risk that the ammunition will “self-ignite”, with disastrous results.

Electronic equipment affected - set values can change

When there are rapid changes in temperature, the trimming of electronic equipment can be lost.

Amongst other things, frequencies in radio equipment can be lost so that all the settings must be redone.

Cold is detrimental to lubricants and oils

At low temperatures, lubricants can be reduced and consequently lose their lubricating properties. At high temperatures, there is an increased risk of mould.

Ozone

Can damage rubber, plastic and fabric.

We humans need the ozone layer encircling the earth to protect us from ultraviolet light. We also “create” ozone through electric generators, transformer stations and the like.

The problem with ozone is that it is detrimental to many plastics and rubber materials.

Ultraviolet light

Ultraviolet radiation causes chemical reactions, which can increase the risk of equipment starting to oxidise.

Methods of dehumidification

To reduce the risk of damage and meanwhile increases the accessibility of the equipment, FMV has developed different methods of storage.

The most important method is to dehumidify the equipment. In everyday terms this is called the dry air method.

This method is to store equipment in low relative humidity or to create an environment with low relative humidity directly inside the equipment.

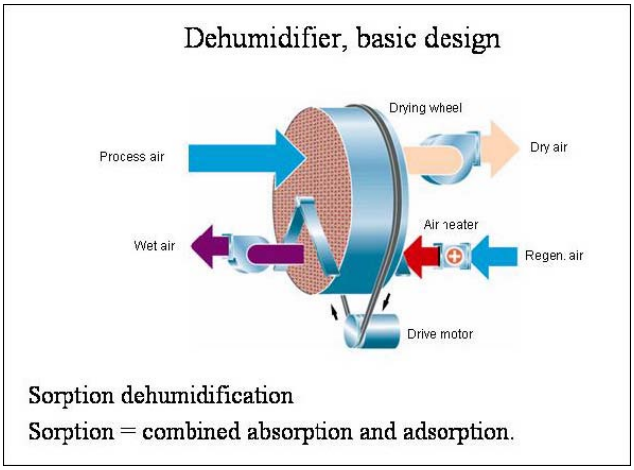
This can be achieved in two different ways. One is static dehumidification. This uses an absorbent material, a desiccant, in the area where the equipment is stored or the equipment itself has desiccant cartridges inside. Small bags of desiccant can also be placed inside the box in which the equipment is stored. The problem with using desiccant is that it becomes “saturated” with moisture relatively quickly and is no longer effective. At that stage they must be replaced with new ones. You’ve probably seen small bags inside boxes containing a new camera or a new telephone. These bags can be saturated after just a few days and won’t be any good after that!

A much better and reliable method of dehumidification is dynamic dehumidification with a sorption dehumidifier. Put simply, this is a dehumidifier with a moisture absorbent rotor that removes the moisture from the air. The sorption rotor is impregnated with a hygroscopic substance and contains a number of small passages through which the air flows.

The rotor moves at 10 revolutions per hour and is normally divided into two zones.

- A working zone, where the rotor takes out moisture from the air – process air – and blows it out as dry air.
- A regenerating zone, where heated air – regenerating air – takes up the moisture from the rotor and blows it out as warm – damp air.

The sorption humidifier works excellently from -40° C up to +40° C.



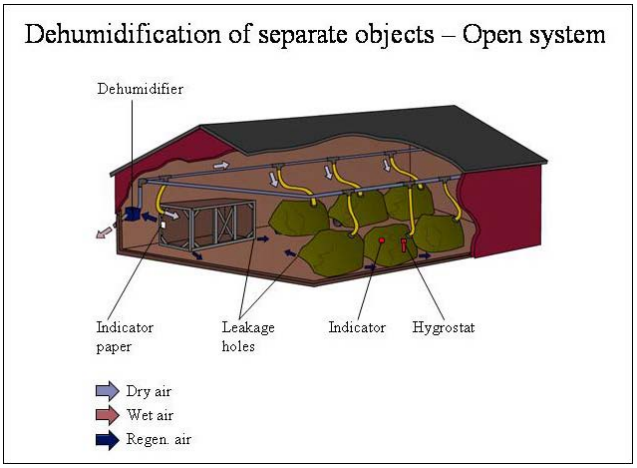
Another method of dynamic dehumidification is condensing dehumidification or refrigeration dehumidification. This method is not suitable for use in our climate has there is a risk of the condensation freezing already at + 8° C and preventing the dehumidification process. Suitable applications are in spaces with high humidity over 80% RH in combination with high temperatures in excess of 20° C.

Relative humidity can also be reduced by heating the air. This method is very expensive and inefficient as it only reduces the relative humidity and not the physical

water content in the air, nor does it lower the dew point. To maintain 50% relative humidity in a storage room through heating, the indoor air must be heated on average at least 7° C above the outdoor temperature throughout the year.

Dehumidification of equipment in storage

Until the 1980s, the Armed Forces dehumidified only a small proportion of equipment in storage. This equipment was often stored in old boxes, which were unsealed and could not be dehumidified entirely.



Dry air was delivered to the equipment through a system of pipes. Quite simply, dry air boxes were constructed from a simple wooden frame and plastic. The boxes held radio sets, binoculars, small generators, spare parts and maps. The dry air boxes were also supplied with dry air through a system of pipes.

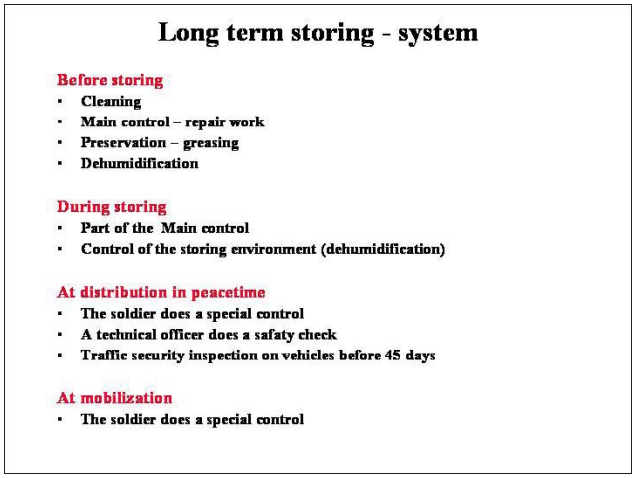
Something called a hygrostat sensed the relative humidity - RH - and started the dehumidifier when it rose above 50%. The dehumidifier was stopped when RH dropped below 50%.

Nowadays, equipment is no longer stored in these simple boxes and the number of stores has been reduced. The stores are now fully dehumidified, i.e. the whole storage facility is dehumidified. The figure shows a storage facility with a volume of around 50,000 cubic metres. It is supplied with dry air from 11 dehumidifiers, which remove 2 tons of water from the storage facility in everyday!

The Armed Forces also use other methods of storage

- Refrigeration Food, medicines
- Freezing Dry batteries
- Frost free storage Heating cabinets – Acid for dry lead batteries

Thanks to dry air we now have a rational system for long-term storage. The methodology is illustrated in the figure below.



Through these measures for storage and a good environment, equipment can be kept for many years without the need for maintenance, see the examples below.

Maintenance intervals for materiel in dry air stores	
• Radio links	4 years
• Radar stations	4
• Optronic, Optical materiel	4, 12
• Spare parts and tool kits	8
• Missiles	1, 4
• Modern Howitzer	4, 12
• Small arms	4, 12
• Ammunition	2, 4
• Combat vehicles	2, 4
• Cross-country trucks	4, 8

Dehumidification of equipment in use

With our good experience of dry air for long-term storage of equipment, we began to think about also dehumidifying equipment that is used every day for training. We began to conduct trials on ground equipment containing lots of electronics and on airborne equipment.

Trials on ground equipment were conducted at S1, Lv6 and P4. The equipment was connected to dry air overnight, at weekends and during other stops in training. The equipment was fitted with connections for dry air supply so that the hose with dry air could be connected and disconnected quickly. We conducted comparative trials for a whole year with half of the qualified equipment connected to dry air while the other half was parked without dry air.

We soon saw the advantages:

- The maintenance costs for electronic equipment were cut by 25%!
- The reduction in faults meant there was more time for training.
- The equipment worked more reliably.
- The troops also noticed some marked changes.
- At Lv6, the battalion commander claimed “we’re shooting better with dry air”. The radar and other electronic equipment were working faster so that the targets were pinpointed in a shorter time.
- At P4, they quickly noticed a pleasant effect that might not have been so important technically but was good for the soldiers’ well-being. When the soldier took his place inside the tank, he didn’t get his backside wet any more – 50 tons of steel can give lots of condensation! This experience says more than that the relative humidity was at such a level that the tank’s electronics would not be damaged through corrosion and oxidation.
- Most units now have canopies under which tanks, staff huts, radar stations, telecommunication containers, etc. are parked.

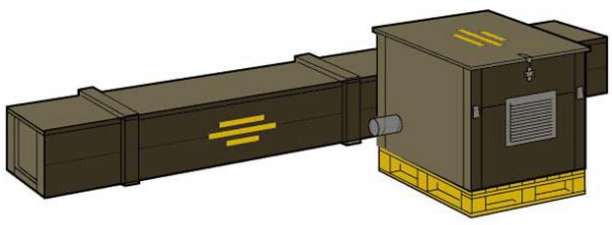
Partial Dehumidification - Active

The illustration shows a combat vehicle 90, the first combat vehicle in the world that has been designed with a view to dehumidifying. Dry air is distributed easily throughout the vehicle and there are also connections for the dry air hose directly in the chassis.

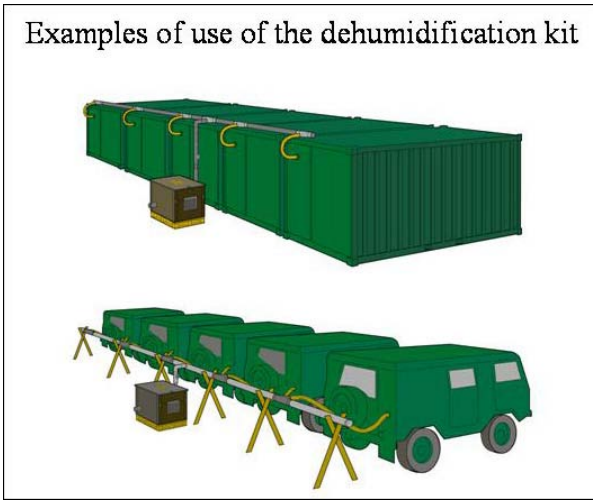
Defence forces are taking part increasingly often in peacekeeping operations abroad. This often takes place in countries with hot days and cold nights. This is a good basis for condensation, which accordingly causes problems for the electronics and ammunition.

FMV has therefore developed a system for dehumidifying equipment while on assignments abroad.

Materiel in use - Dehumidification kit

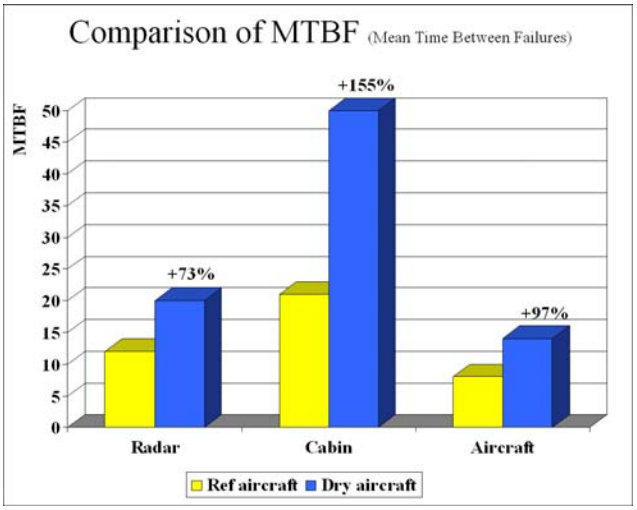


The kit contains a dehumidifier, hygrostat, pipes and all other components needed to construct a simple dehumidification installation.



The trials conducted on training aircraft used the same principles as the ground equipment. The aircraft was connected to a dehumidifier as soon as it was standing on the ground. With all the electronics onboard, an aircraft operates in the most difficult of environments. This can be -50° C at a height of 10 000 meters and + 40° C while standing in the sun on the ground, while the systems in the aircraft can be very hot after the flight. This causes high humidity and condensation.

A positive result was quickly obtained. The mean time between faults - MTBF - increased dramatically, while maintenance costs were cut!



FV invested 3 MSEK in dehumidifying installations, a cost that was paid off after three months of flying thanks to the lower maintenance costs.

FV has now been using the dry air technology on the Draken, Viggen, Hercules and radar planes with very good results. Sweden has been the forerunner for other countries with regard to dehumidifying aircraft.

The development of a dehumidifying method for Gripen has now started.

Ships and boats are also dehumidified. This applies to boats in dock as well as boats in use.

In marine environments around ships, relative humidity in the air and in the ships is high.

Not least on the bridge and in the wheelhouse, where there is plenty of electronic equipment. Moisture is also a problem in the hold, where equipment and ammunition is stored. Corrosion and mould will soon take its grip in these areas because of the condensation unless dehumidification is provided for.

Storage trials

FMV has conducted three extensive storage trials, the first for a period of eight years and the two subsequent ones for four years each.

The objectives with these storage trials are as follows:

- Can equipment be stored for long periods with maintained accessibility?
- The difference between storage with and without dry air.
- What materials, e.g. rubber, plastic, metal, are the most suitable to use for military purposes?
- Do modern electronics and new materials put other demands on storage?
- Particulars for designing methods of storing equipment.
- How is equipment affected by the environment, such as humidity, pollution from industry and agriculture?
- Investigate how gases in the air, ozone and radon, affect the equipment.

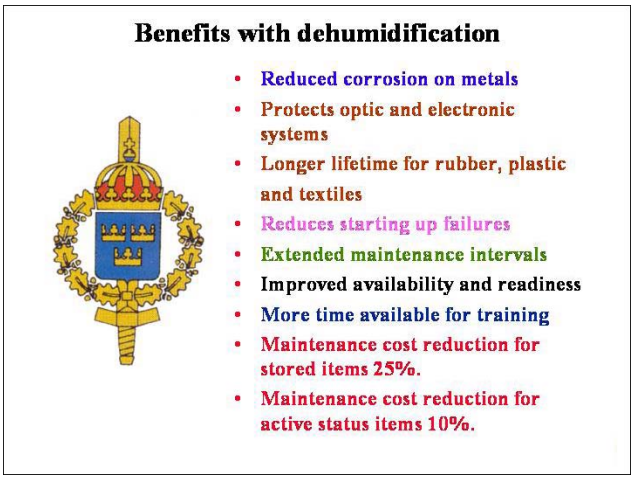
Trials are often conducted in cooperation with Swedish industry, which takes part in evaluation and analysis.

Economy

The Swedish defence can save large amounts of money through the use of dry air for equipment in storage and in use. Maintenance activities before and after storage have been reduced while it has been possible to extend maintenance intervals. Analyses that have been carried out over the years show that the annual saving has been between 200 MSEK and 400 MSEK.

Summary

Using dehumidification technology gives the following positive effects.



International interest

As Sweden started using “dry air” more than 50 years ago, we have the experience and the expertise that an increasing number of countries wish to study. Over the years, FMV has been in touch with around 40 different countries all over the world.

We all have the same environmental problems or even worse!