Museum Archive Dehumidification in Hot & Humid Climates

B. K. Browning, PE Principal Engineer KWR Services Austin, Texas

ABSTRACT

This paper discusses some of the difficulties found with a desiccant dehumidification system installation in a museum archive. The operator of the system reported shutting down and abandoning the system within the first year after installation. Portable mechanical dehumidifiers were used for roughly six years until a retrofit project brought this to management's attention. Investigations revealed that the dehumidification system design and installation were causing water to condense in the regeneration air ducts which then drained through the desiccant dehumidifiers and regeneration air ducts. Recommended corrections are discussed but have not been implemented and tested.

INTRODUCTION

Museum archives require special environmental conditions, frequently below the outdoor dew point in hot and humid climates. Additionally, some of the collection in the archive may be considered high value or irreplaceable. The result can be archives that are susceptible to water problems from some unexpected sources. This paper discusses some of the water problems found in museum archive that had been updated to maintain an irreplaceable collection of acetate and nitrate based photographic materials. Based on the problems found, recommendations for correction of these archives and general archive recommendations are discussed.

Background and Space Description

A museum archive was updated in 1994-1995 to install new unit coolers and desiccant based dehumidifiers to provide better humidity control. The archive consisted of two rooms on the top (third) floor of the museum. The first room is 30' x 28' x 7' room to be maintained at 60 F +/- 2F and 50% +/- 2 % relative humidity. This room is intended to store acetate based materials. The second room is 14' x 24' x 7' accessed through the 60 degree room. The second room is maintained at 50 F +/- 2F and 50% +/- 2 % relative humidity to store nitrate based materials. (The selection of those conditions was made by the archivist for their specific needs. Discussion of these is beyond the scope of this paper. More information can be found in the ASHRAE Applications Handbook and the Image Permanence Institute[1].) The collection of materials in both rooms is considered irreplaceable so maintaining the archive temperature and humidity conditions are extremely critical. Completely redundant systems were installed to prevent a loss of space conditions to equipment failure. A diesel generator was installed to provide power in case of failure of the power grid. Maintaining the archive temperature and humidity are a very high priority. Prior to the 1995 update, the archive conditions were maintained by a single DX unit cooler per space. There was neither redundancy nor any special humidity control. Humidity control was a byproduct of cooling. The desiccant dehumidifiers were added to correct poor humidity control. The performance capability and reliability of the desiccant dehumidifiers appeared to be a good match for the archive. The design layout of the desiccant dehumidifier installation is shown in Figure 1. The capacity of the dehumidifiers was controlled by building energy management and control system (EMCS) switching on a dehumidifier when the humidity exceeded the set point and switching it off below the set point. The EMCS also detected dehumidifier failure and switch on the backup dehumidifier. The EMCS was set to lead/lag the dehumidifiers and switch the lead unit every week.

History

The operator of the system found a dehumidifier down within the first 60 days. The contractor for the project went bankrupt at about the same time so warranty corrections were extremely difficult. Over the next 60 days, the other dehumidifiers had failed – some multiple times. The building operator wisely decided to provide another means of humidity control and brought in portable dehumidifiers. Through the course of the first year, the operator replaced many electrical components in an attempt to keep the desiccant dehumidifiers running. After the first year he abandoned the desiccant dehumidifiers and relied solely on the portable dehumidifiers. It appears this problem was considered 'under control' and never reported to management.

In late 2001 a retrofit project was started to replace the original unit coolers that were used for the backup cooling. During the pre-design investigation, it was found that all four of the desiccant dehumidifiers

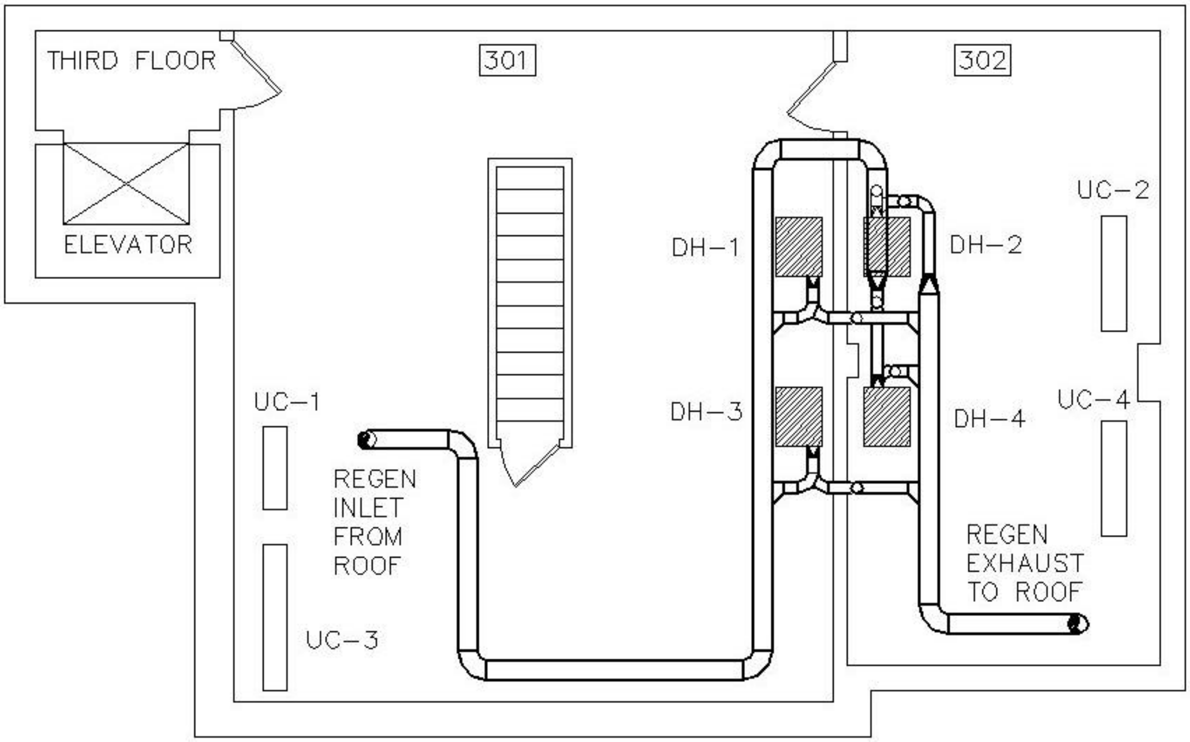

Figure 1 – Plan view of third floor archives showing desiccant dehumidifiers and regeneration air duct layout. Room 301 is maintained at 60°F and Room 302 is maintained at 50°F.

were shut off at the electrical disconnects. Current operating personnel did not recall the desiccant dehumidifiers had ever operated. Troubleshooting the units showed all four had various failed electrical components. Conversations with the service provider revealed the past history of component failures. Conversations with the dehumidifier manufacturer's representative and review of the dehumidifier unit documentation did not point to a root cause.

Since the root problem and scope of the correction work required to the dehumidifiers could not be determined on the current retrofit budget & schedule, it was decided to only include an 'inspect and report' factory service call.

The dehumidifier factory technician's report indicated two problems with the design / installation. First, each dehumidifier was connected to a common supply duct for regeneration air and a common exhaust duct for regeneration air. No control or back draft dampers were specified or installed. Because at least two dehumidifiers (the redundant units) will be off at any time, there will be wet regeneration exhaust air flowing backwards through those units any time another unit is on. The regeneration air exhaust will condense in the dehumidifiers that are not running. The result was condensed water running through the dehumidifier and shorting various electrical components.

Second, the reactivation inlet had an air filter installed at the unit. Due to the design of the unit and the installation location, access to the air filter was completely blocked. Current facility operating personnel did not know there was a filter on the units. The original operator did remember there was a filter but had long ago abandoned the units so he didn't pass that information to the new operators.

Plans were made to install control dampers in the regeneration air exhaust of each dehumidifier. The control dampers were to be wired in parallel with the command for that particular dehumidifier so the damper would remain closed unless that dehumidifier was commanded on. The inaccessible air filters were to be replaced with a single filter in the common regeneration inlet duct. Since the space conditions were being maintained by the portable dehumidifiers, these changes were to be made as time and budget allowed. Due to continuing personnel turnover and budget constraints, these have not been completed. Figure 2 shows dehumidifier DH-3 during control damper installation.

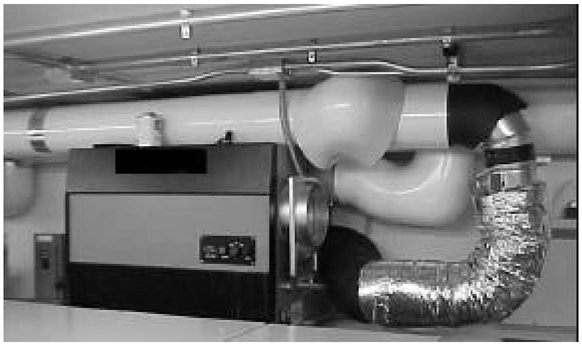

Figure 2 – Dehumidifier DH-3 during regeneration control damper installation.

In May 2003, the archivist reported some materials in the collection were found wet. Immediate investigation by the building operators did not reveal any water leaks, roof leaks, or any obvious source of the water. The wet materials were relocated pending a more detailed investigation. That investigation showed that the water was coming from the regeneration air duct for the desiccant dehumidifiers. (Note - these dehumidifiers were still turned off.) Figure 3 is an infrared picture showing the water level in the regeneration inlet air duct. Figure 4 shows the regeneration air duct above the shelves where the wet materials were found. The immediate problem was that water from inside the regeneration air ducts was leaking on to the archive collection.

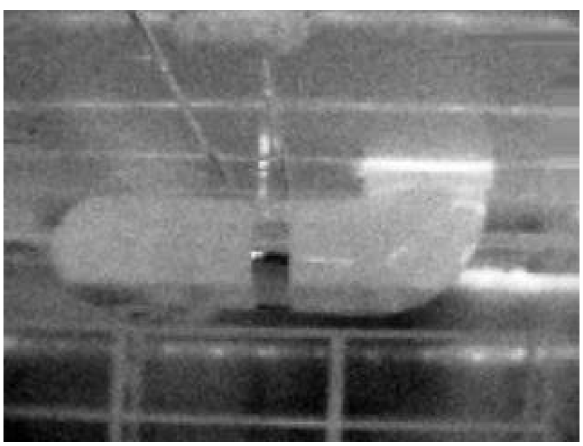

Figure 3 – Infrared picture of regeneration air inlet. Water level is visible inside insulated duct.

During dehumidifier installation in 1995, the regeneration air ducts were tapped into existing exhaust fan ducts that ran from the archive to the roof. Figure 4 is the view of the regeneration air inlet from inside the archive. Figure 5 is the view of inside the duct from the roof. These existing ducts were completely un-insulated. The ends of the existing duct that were exposed inside the archive would be at 50 F or 60 F at all times. The new regeneration air ducts were insulated with one inch of Armaflex sheet insulation. The building operators found that they could mop up any water standing in the duct but more water would be found an hour later. For such a critical space a detailed investigation / analysis was warranted.

Figure 4 – Visible picture of regeneration air inlet from inside archive. Water damaged materials were found on shelves in background. This is the same duct as Figure 3.

Figure 5 – Picture of regeneration exhaust viewed from roof. Water level is visible inside duct. Hose at lower right is pressure measurement reference.

INVESTIGATION / ANALYSIS

Collection of existing documentation was of limited value. No design intent / basis of design[2] recommended by ASHRAE Guideline 1 were found in the Owner's project documentation. The mechanical engineer of the 1994 retrofit was contacted to see if such information could be found. Records on such an old project were no longer available. However, the engineer was kind enough to provide a copy of the project drawings.

The drawing schedule for the dehumidifiers showed some unexpected operating conditions. The process air is shown to have an external static pressure of 1.75 inches. Since there are no ducts shown on the process side of the units, the ESP should be near zero. The regeneration air shown in the schedule indicates all regeneration air will enter at 10FDB and 6 grains per pound. Those are very unusual conditions for a hot & humid climate, even in the winter. The ASHRAE 99.6% heating design condition for this area is 25 F[3]. The schedule appears to indicate the design point is for winter in a heating climate.

The manufacturers of these desiccant dehumidifiers and similar units were contacted for design guidelines. All provided sales literature and a unit price. None provided design guidance such as recommendations for installing the unit inside or outside the conditioned space, installing the ducts inside or outside the conditioned space, providing additional insulation on the dehumidifier housing, condensation control features, etc.

The ASHRAE Systems and Equipment Handbook[4], both the 1996 and 2000 versions, include cautions about condensation in duct systems for desiccant dehumidifiers. It is not know if the 1992 version (which would have been available during the design in 1995) includes such cautions. The later versions also advise to include filter access space in the design and installation.

Site investigation showed many indications of high moisture problems in the archive space. Wall stains as shown in Figure 6 were found in many locations. The cause and time of the stains could not be determined. Some of the stains had been previously outlined and dated to determine if the stains were growing. No indications were found that the stains were continuing to grow. Figure 7 shows a control box that was clearly filled with water at some point. The box was dry during our investigation. All of the observed water marks may have been from roof leaks or other past issues not related to the current findings.

Some quick estimates were made to determine the potential for water condensation in the ducts. Assuming two of the dehumidifiers were operating at the summer dew point design condition (300 cfm at 80 FDB and 75FWB cooled to 60 FDB and 60 FWB) the rate of condensation would appear to be limited by the rate of water in the moist air entering the regeneration duct. The estimate shows that roughly a gallon of water per hour would be deposited in the regeneration duct. Since there are no drain provisions, there is very little tolerance for condensate and this rate of condensation would cause problems.

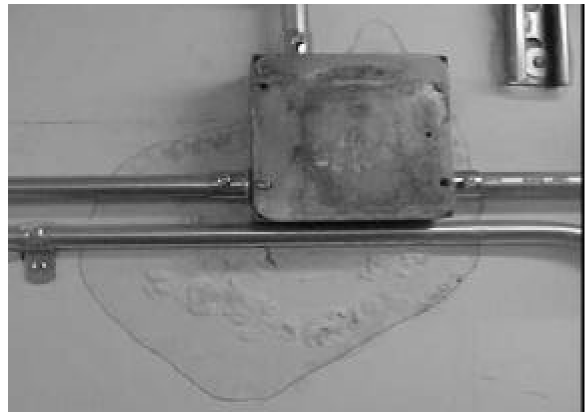

Figure 6 – Water stains at penetration of archive wall to interior of building.

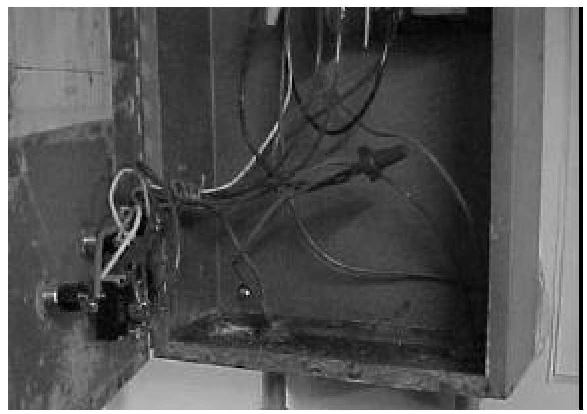

Figure 7 – Control box corrosion indicating it had been filled with water to top of door flange.

A bigger problem appears to be when the dehumidifiers are NOT operating. Modeling the duct as a horizontal cylinder in free convection with a constant inside surface temperature and assuming the condensing heat transfer coefficient is much higher than any other thermal resistance, the rate of water condensation from saturated air at 74 F was estimated at around 20 gallons per hour. This estimate assumes the outside air and water vapor can freely replace the moisture that condenses and the condensed water runs out instead of filling the duct and reducing the heat transfer area. Obviously these assumptions represent a worst case condition. However, this estimate also shows that when the outdoor air is saturated (typical summer morning condition) the cold duct will condense water at a rate limited primarily by the rate wet air can enter the duct.

On the regeneration side the situation was expected to be worse. However, similar estimates for the regeneration air heat loss and leaving air dew point show that there should be no condensation even at the ASHRAE dehumidification design point of 80FDB and 75FWB. The leaving air dew point is estimated to be 86F and leaving air dry bulb is 200 F. Unfortunately, these estimates only apply while the dehumidifier is running. Condensation in the regeneration exhaust duct has to be expected when the unit turns off and leaves the duct full of warm wet air with lots of time for heat loss through the duct insulation. The problem of condensation in the duct when the unit is not running would be similar to the regeneration inlet with outdoor conditions inside the duct and 50F temperature outside the duct insulation.

Based on these estimates, the regeneration ducts were sealed at the roof to prevent the entry of wet outside air. The seal was made with duct board and mastic until a permanent solution was implemented. Within a day the electrical conduit to the roof mounted condensers had filled with water and were leaking into the archive. Pressure measurements with respect to the outside indicated the archive was depressurized by 12 Pascal (0.048 IWC)! When the regeneration ducts were sealed the electrical conduits were the next best path for outside air to try to 'fill' the depressurization. Since there are no exhaust fans shown on the drawings or exhaust grills found in the archives, the depressurization was not expected. The conduits were replaced and sealed closed with silicon caulk to stop the water leakage.

An exhaust fan was found that appears to draw air from a plumbing chase adjacent to the 50 F room (shown between UC-2 and UC-4 in Figure 1). This plumbing chase has a 24 inch square access panel that connects the chase to the 50 degree room. The access panel was also allowing the exhaust fan to depressurize the archive spaces. Figure 8 shows a picture of the access panel. The access panel was sealed with duct board.

After the plumbing access panel was sealed, the archive was measured to remain between + 2Pa and -2 Pa. It was not determined if the pressure variations were due to mechanical equipment interactions or other sources such as wind, stack effect, or instrument drift. Water was no longer being drawn into the archive and the investigation was stopped.

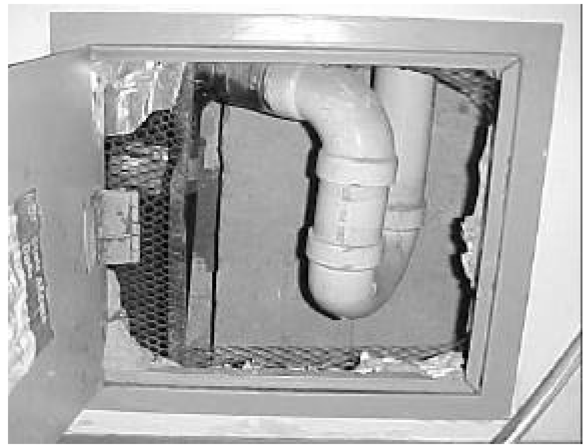

Figure 8 – Plumbing access panel that allows exhaust fan to depressurize archive.

Recommendations and Solutions

The existing dehumidifiers appear to be capable of controlling the humidity within the archive. The problem is how to install the dehumidifiers so that the regeneration air doesn't cause water damage and other trouble. The following recommendations are made:

1) Remove the air filters at the regeneration inlet of each dehumidifier and replace them with one large filter at the regeneration inlet on the roof.

2) Add a back draft damper or control damper at the exhaust of each dehumidifier. If control dampers are used they should be wired in parallel with the command signal for that dehumidifier so the damper only opens when that unit is operating.

3) Add a low leakage control damper at the regeneration inlet and exhaust on the roof. These dampers must open when any unit is on and close when all units are off.

4) Slope the regeneration ducts and add condensate drains at all low points. Since the archive is a place where water is to be avoided and water leaks are major problems, condensate drain design and installation will be a difficult task. Because the ceilings are only 7' high, it may not be possible to provide condensate drains and maintain enough storage space and walk ways.

5) If possible, move the dehumidifiers and especially the regeneration duct out of the archive space. Condensation inside these ducts will always be a problem because the archive space is maintained below the

outdoor dew point temperature for most of the year. Unfortunately, this may not be possible for this existing museum archive.

6) For projects of this critical nature provide full design through warranty commissioning. The cost of commissioning should be much less than the cost of corrections even before the archive and its collection is considered.

After implementation of corrections, the dehumidifiers should be repaired. The operation of the desiccant dehumidifiers should be monitored for some time before the portable dehumidifiers are removed from the space.

Providing condensate control in this existing facility will be very difficult without major impact to the function of the archive. However, moving the dehumidifiers and regeneration duct outside of the archive space will not be a trivial project either.

General recommendations for archive spaces include:

1) Design guidance is given in the ASHRAE handbooks and most by most manufacturers. Many problems can be avoided by using these references.

2) Design Intent and Basis of Design documents may seem like excessive and unnecessary effort but they focus the designer's attention on critical issues at a point when the issue can be most effectively addressed. These are highly recommended on all projects and especially for critical projects such as archives.

3) The design performance must be evaluated at all conditions –especially off design points like startup, shut down, and system standby. Hot & humid climates frequently are near saturation conditions for several hours every night/morning, but those are conditions are rarely considered in the design documentation.

4) The possibility of condensation inside ducts should be evaluated. If condensation is likely or even possible, the duct must be designed to handle that condensation.

5) Maintenance access space can be vitally important to the operation of the system. However, the installers are rarely concerned with maintenance space (such as air filter access) since their primary responsibility is speed of installation. The designer, construction administrator, and commissioning authority must verify the installation is maintainable.

6) Small details can cause major problems. Details such as duct routing, insulation levels, electrical conduit routing, plumbing access panels, etc. can cause major problems. Unfortunately, these details are usually left the installer in the field that is likely to have the least information for making these decisions. The level of design effort and submittal review should be much higher than a 'typical' project.

7) All critical projects should be commissioned from pre-design through the end of warranty. Identification of problems described in this paper should be made before installation when corrections are more easily made. Construction phase commissioning could have identified problems after installation, but they would be difficult to correct at that point.

CONCLUSIONS

Critical spaces need critical designs including consideration of off design point conditions. In this case, a good equipment selection was made but the rest of the design and installation caused many problems. Commissioning, especially design phase commissioning, would have helped this project by identifying most of the problems found. It should not take years for identification and correction of problems in such a critical space.

REFERENCES

[1] Image Permanence Institute, Rochester Institute of Technology, Rochester New York, *Storage Guide for Photographic Materials*

[2] American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc., 1996 *Guideline 1-1996*

[3] American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc., 2001 *Fundamentals Handbook*, Chapter 27

[4] American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc., *HVAC Systems and Equipment Handbook*, 2000, Chapter 22