EXAMINATION OF RELATIVE HUMIDITY AND TEMPERATURE LEVELS AT THE SOUTH CAROLINA STATE MUSEUM

RESEARCH CONTRIBUTION 17

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Chicora Research Contribution 17

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Introduction

This study was prepared at the request of Ms. Debi Hacker, Conservation Administrator, South Carolina State Museum and is in response to a three month period of temperature and relative humidity monitoring at the Musuem which has shown widely fluctuating levels. The purpose of this study is to discuss the observed conditions and offer an assessment of the problem. In addition, recommendations are offered in several areas.

The readings used in this report were taken using a digital thermohygrometer, an aspirated psychrometer, a sling psychrometer, and two hygrothermographs. Instruments have been cross checked and calibrated with the result that the readings discussed in this study are accurate to $\pm$3% relative humidity and $\pm$2°F. Considerable assistance was provided by Mr. Buddy Hana, A/C Consulting and Service, of Columbia, South Carolina. Mr. Hana is an HACV engineer with over 20 years experience. He has visited the Museum on two occasions to discuss HACV problems and has provided 6 hours of pro bono consulting. While he has provided considerable assistance in understanding the Museum's system, this report represents the opinions only of the author.

Relative Humidity and Temperature

The relative humidity (RH) is the amount of moisture present in a given volume of air expressed as a percentage of the maximum amount of moisture which can be present at a particular temperature. Thus 20% RH indicates that the air contains only 20% of the moisture content it can hold at that particular temperature and is considered dry, while 80% RH indicates that the air contains 80% of the moisture content it can hold at that temperature and is considered very moist.

The temperature will affect RH values and, in fact, Dr. Elias J. Amdur (1964:60), the Chief Engineer of Honeywell, Inc. clearly states that, "good relative humidity control depends on good temperature control" and that high quality temperature control is an essential first step to controlling RH. Humidity may be controlled in two ways. First, the quantity of water may be held constant and the temperature may be altered. For every 1°F change in temperature there will be a 1.5% change in RH. As an example, added or removed. The second technique used in controlling humidity actually removes moisture and is used by dehumidifers (whether as small room models or large features built into HACV systems). The moist air is drawn over low pressure refrigeration coils which cool the air to below the dew point resulting in water being condensed from the air. The air then passes over the high pressure coils which give back the heat which was removed from the air. As a result the air leaving is lowered in humidity, but at about the same original temperature (or frequently slightly warmer).

Acceptable Temperature and RH Levels and the Consequences of Deviation

The human body is fairly sensitive to temperature deviation, changes of as little as 2°F detectable by a few individuals and changes of 5°F detectable by most people. As a result, for human comfort, temperature variation should be held to a yearly variation of 10°F (Buck 1964:53). John Purvis, State Climatologist, suggests a temperature of 72°F (with a low RH) is ideal for people, so a temperature range of 67 to 77°F may be suggested. This upper limit, however, is uncomfortable for many people, particularly if walking through galleries, and since biochemical deterioration is increased with higher temperatures, Thomson (1986), Scientific Advisor to The National Gallery, London, recommends a maximum temperature of 75°F for collections. The National Conservation Advisory Council has endorsed a standard of 65±5°F (Matthai 1978: 21) and Ritzenthaler (1983:31) recommends a temperature of 67±2°F for manuscript collections, while photographic collections should be kept even cooler. Given the constraints of energy use and the realization that, overall, temperature is of less concern than humidity, a standard of 70±5°F is reasonable for the Museum. This variation should be seasonal, with a **gradual** change. No shifts of more than 2°F should be tolerated in a 24 hour period.

Humans tolerate very broad levels of humidity, although levels over 70% are usually considered uncomfortable and discomfort may begin at even lower levels. Most museum objects, however, are highly sensitive to humidity levels (Buck 1964:54). There are three modes of deterioration that are influenced by RH levels: changes in size and shape, chemical reactions, and biodeterioration. Each is discussed below in turn.

All moisture-absorbent (hygroscopic) materials (such as wood, bone, ivory, parchment, leather, textiles, basketry, matting, adhesives, and paper) swell when the RH rises and shrink when the RH falls. This causes warping, dislocation between parts, splitting, breaking of fibers, and so forth. To illustrate the significance of humidity control, Thomson notes,

> the same amount of expansion across the grain follows either from a rise of 4% RH or a rise of about 10°C [34°F] at constant RH. But whereas the RH change is the kind of fluctuation one gets with

> the best air conditioning, 10°C represents a very large change in temperature (Thomson 1986:68).

Table 1 illustrates the dimensional changes in various objects caused by environmental fluctuations.

Change	along grain	across grain
5°C wood	.002%	.02%
10% RH oak	.40%	.70%
10% RH mahogony	.30%	.45%
10% RH paper	.05%	.30%
10% RH canvas	.05-.10%	
10% RH ivory	.30-.40%	

Table 1. Dimensional changes in various museum collection materials (from Thomson 1986:224-226).

Normally it is desirable to maintain a RH level for most of these objects which will ensure the stability of their original "workshop moisture content" (Buck 1964:55). This is estimated to be between 9 and 12%, which requires a humidity level of not less than 45% RH (Buck 1964:54; Thomson 1986:68, 224). An exception includes photographic collections, which should be held at 25-40% RH (Ostroff 1976:4).

Two very different classes of chemical reactions are encouraged by high humidities: (1) the corrosion of metals, and (2) the fading of dyes and weakening of papers and textiles. Some metals (such as polished steel and unstable bronze) corrode more actively at humidity levels about 30-45% (Buck 1964:56; Matthai 1978:14; Thomson 1986:84). Even silver is thought to tarnish more rapidly at higher humidity levels. Thomson (1986:85) suggests that most cottons, linens, wools, and silks fade more rapidly at humidities above 45% RH. Ostroff also notes another chemical reaction danger from high humidity levels,

> sulfur dioxide, the principle form in which sulfur reaches the atmosphere, can combine with atmospheric oxygen to form sulfur trioxide, which, combined with moisture, forms the corrosive, sulfuric acid; metallic impurities can catalyze this reaction. The rate of sulfur dioxide pickup accelerates with increasing humidity and temperature (Ostroff 1976:3).

Perhaps the most significant deterioration influenced by the RH is biodeterioration, including mold, bacteria, and insect growth. Mold spores are always present in the air and will grow whenever (and wherever) environmental conditions are favorable.

These conditions include a warm temperature (generally above 75°F), moisture (RH above 65%), darkness, and little air circulation. Two authorities suggest that a RH above 60% should be considered dangerous (Ostroff 1976:4; Ritzenthaler 1983:27). Once established, mold growth cannot be erradicated. The traditional use of thymol and other compounds has recently been shown to be totally ineffectual. Dalloff and Perkinson (1977:15) clearly state that "the chief danger of excessive humidity is the growth of mold."

Clearly the maximum RH level acceptable should be below that which mold tends to grow. Ritzenthaler (1983:31) states that "a constant relative humidity of 47 percent ± 2 percent is low enough to avoid problems with mold growth." Others, however, suggest that levels below 60% or even 65% are acceptable, as long as there is control over ventilation and temperature. Thomson (1986) notes that a level of 50±5% RH is acceptable for a mixed collection, although clearly special collections may require special attention. It should be further emphasized that the tolerance of ±5% is based not on any clear, convincing experimental data, but rather on what can **reasonably** be expected from the equipment.

Buck (1964:56) notes that many museums find it impossible to control humidity within ±5% **on a yearly basis** and often the seasonal variation may be as much as ±10% (from about 45% RH in the winter to 65% RH in the summer), but he also warns that these are clearly the outside limits and that if exceeded, "unnecessary damage to some parts of almost any museum collection may be anticipated." Further, this is a seasonal, not daily or weekly, variation and it should occur slowly throughout the year, with changes of perhaps 2% RH per month. Daily fluctuations should not exceed 2-3% RH.

60-Day Trends

With the specifications discussed (70±5°F with daily shifts of no more than ±2°F; 50±5% RH with daily shifts of no more than 3%) and the consequences (irrepairable deterioration of the collections) in mind, it appears appropriate to examine the 60 day trends for the Museum building. These readings began April 2 and continued through June 11, 1987 (actually a 71 day period). These data provide a general perspective of the Museum environment, but fail to reveal small scale variation which can be equally damaging. As a consequence, this section will also examine a 14-day trend for two specific areas, and a seven day trend for another.

The first area to be examined is the 1st Floor Education Hallway (AHU 1-7 feeds this area). This is a basement type area, without windows, to be used by the public, with no Musuem storage or exhibit areas. As a result, temperature and humidity controls should be suitable for human activity, but need not be as greatly controlled as for museum objects. Figure 1 illustrates the trends in this area. The temperature has ranged from 67 to 74°F (mean 70.5±3.5°F). This is not unreasonable for the area's intended use, although there is currently no heating load being placed on the HACV system (the area is unoccupied). It is likely that the

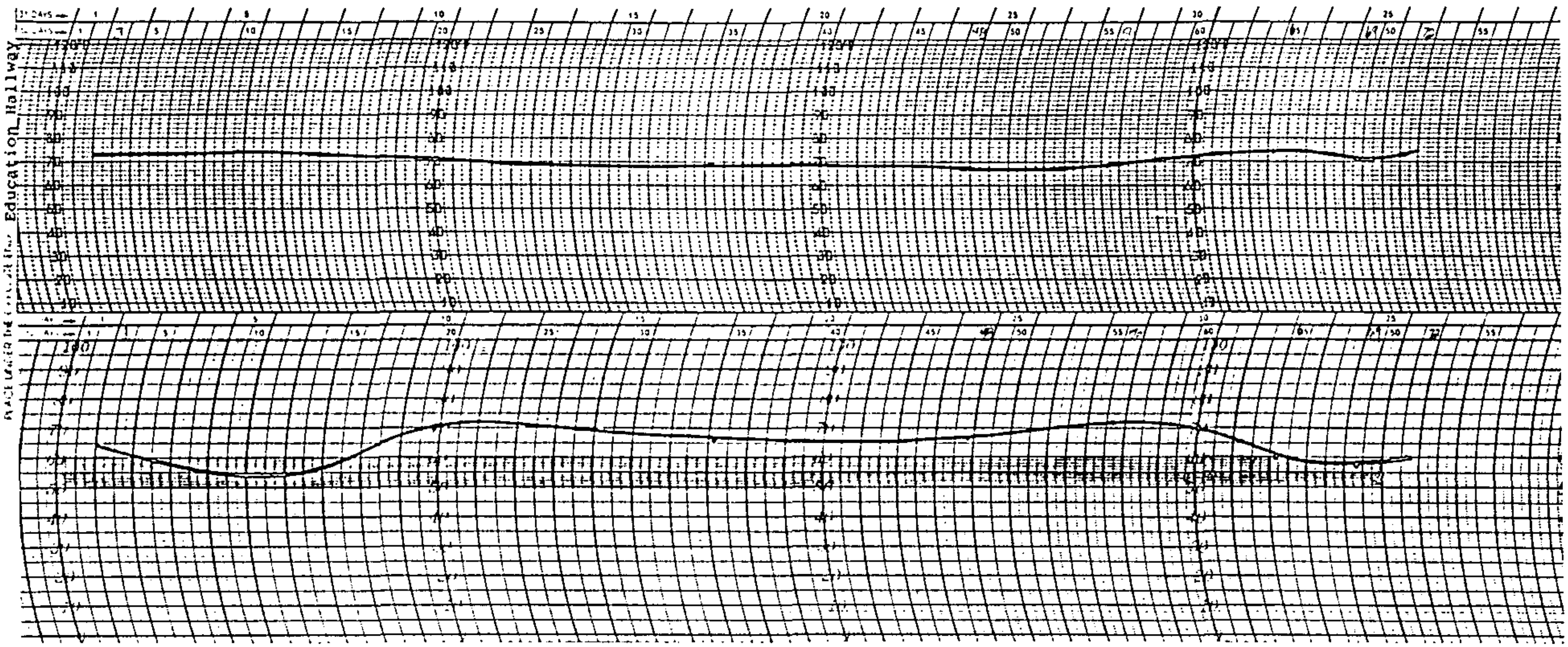

Figure 1. 71-day trend of temperature and humidity levels for the 1st floor Education Hallway.

temperature will increase noticeably once this area is being used. The RH for this area has varied from 54 to 72% RH, with levels above 60% RH for 46 of the 71 days (65% of the time). These levels, which are expected to rise as the area sees increased use, are clearly too high. John Purvis, State Climatologist, notes that levels of 75° F and 60% RH are considered very warm and lead to fatigue. In addition, this environment is condusive to mold growth on the painted walls and in the carpet. This condition is inappropriate for an area designed to be used by children, who tend to be more sensitive to molds. Mr. Hana has noted that a daily range of 50 to 70% RH is not unusual for commercial buildings with reliance entirely on air conditioning for dehumidification. This is a design consideration, however, since building owners anticipate repainting every 3 years and recarpeting every 5 to 6 years. Mold growth, then, is reduced by periods of lower humidity and its growth is tolerated because of planned, periodic rennovations. It seems unlikely, however, that the Museum has the funding to tolerate periodic painting and recarpeting. In addition, this area has humidity control, but that control is not adequately functioning.

Figure 2 illustrates the long-term trend in the 2nd Floor Conservation Department. This area, with exterior exposure and above ground construction, has humidity control (which has been set to maximum dry during the course of this study). The area is fed by AHU 2-5. The temperature has fluctuated from 68 to 74°F (mean 71±3°F), within acceptable levels. The humidity has ranged from 45% RH to 65% RH. While there has been little danger of mold growth, this 20% RH variation over 2 months is unacceptable for museum collections and may lead to severe damage of specimens being treated by the Conservation Department. Examination of a seven day chart (Figure 3) for this area reveals variation from 44% to 77% RH, or 33% over a seven day period. This indicates a severe condition that ranges from too dry to a level clearly condusive to mold growth. The rapid fluctuations are very damaging to collections because of the shrink-swell stresses.

On the 3rd Floor a 60-day trend is available from Collection Storage Room 318 (Figure 4). This area is designed to have sensitive temperature and humidity control and monitoring. It is fed by AHU 3-5. Figure 4 illustrates the trend. Temperature has ranged from 66 to 74°F (mean 70±4°F). These temperature variations are on the outside edge of acceptable limits and should be carefully monitored since there is so little margin of safety. The humidity levels range from a low of 54% RH to a high of 65% RH, a variation of 11% over 71 days. Levels above the Museum specifications and at the very maximum of the safe range have occurred for about 23 of the 71 days (33% of the time).

Figure 5 illustrates the long term trend in the 4th Floor Collection Storage Room 414. This area, like the one previously discussed, was designed to have optimum temperature and humidity controls. It is fed by AHU 4-2. The temperature has ranged from 67 to 72°F (mean 69.5±2.5°F). Humidity, however, has ranged from 55 to 70% RH, a variation of 15% and the humidity levels have

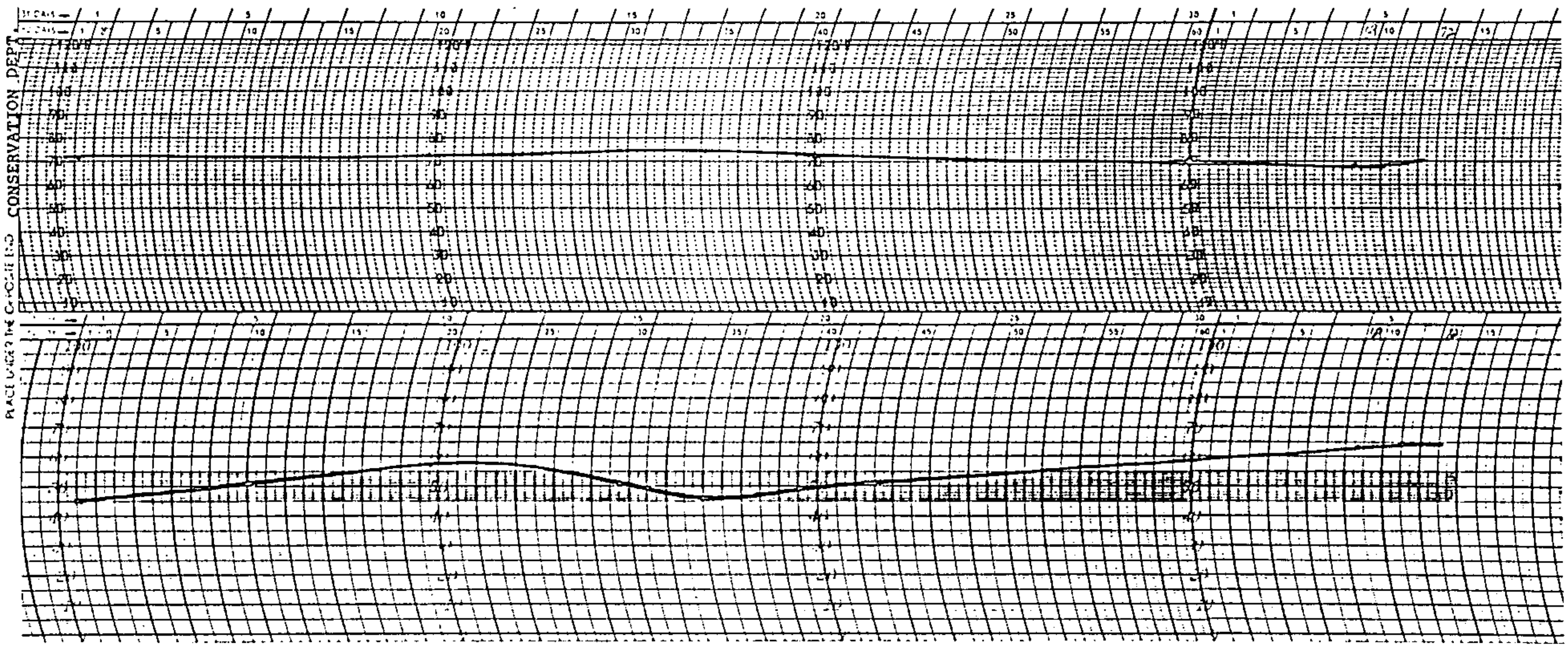

Figure 2. 71-day trend of temperature and humidity levels for the 2nd floor Conservation Department.

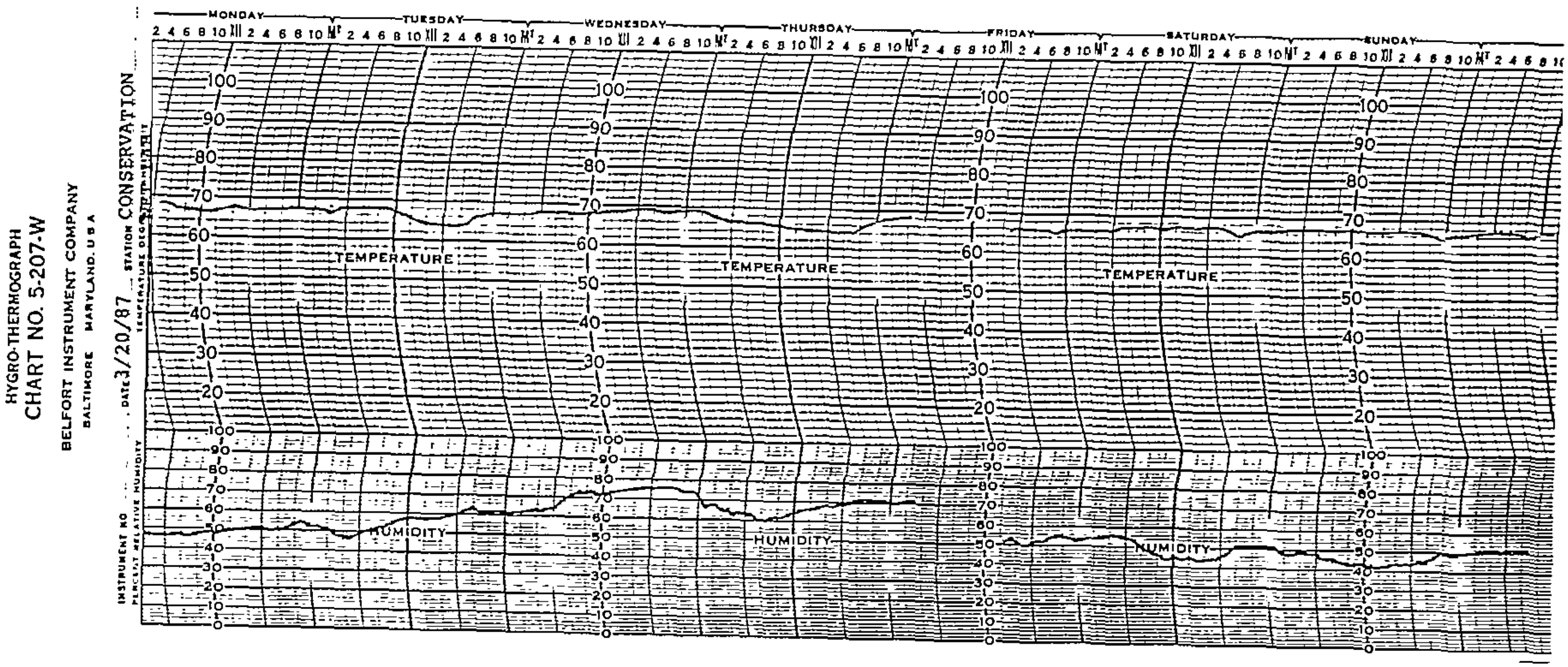

Figure 3. 7-day chart of the Conservation Department (3/20/87-3/26/87).

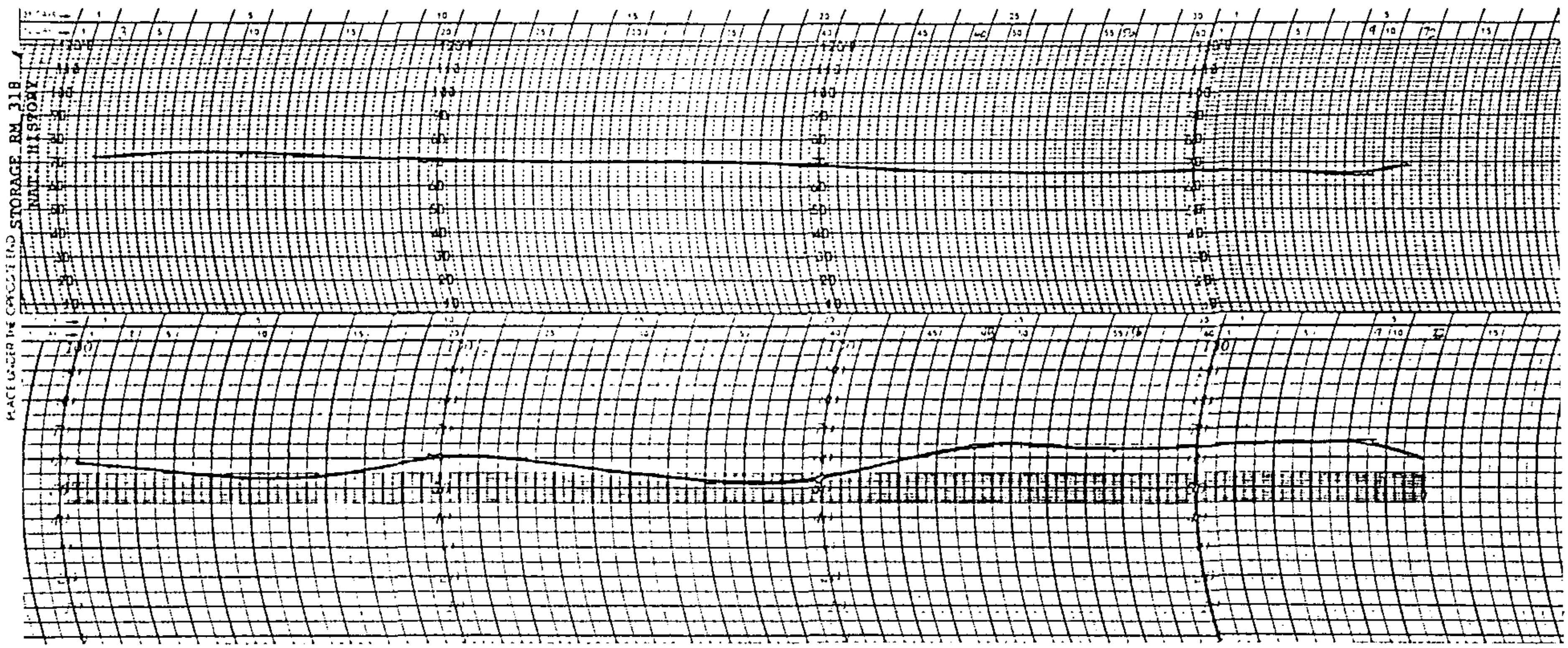

Figure 4. 71-day trend of temperature and humidity levels for the 3rd floor collection storage room 318.

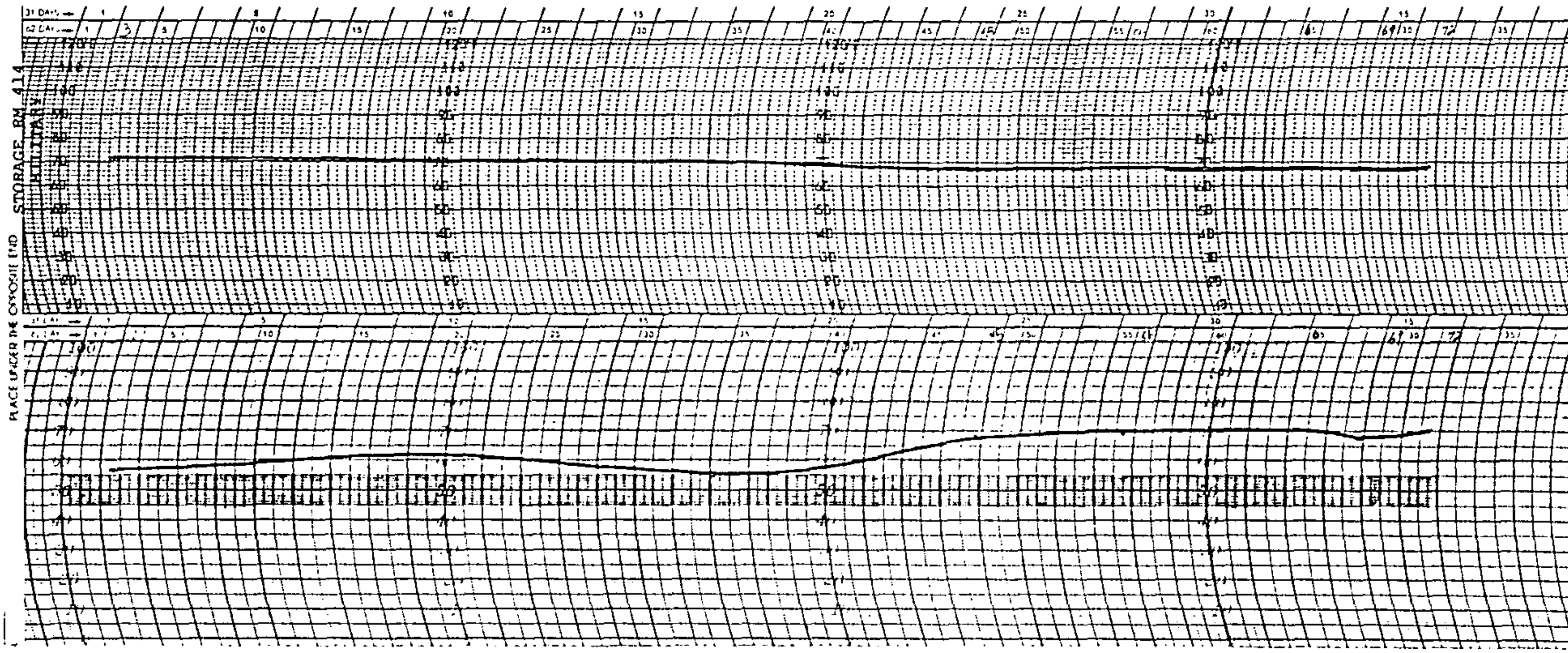

Figure 5. 71-day trend of temperature and humidity levels for the 4th floor collection storage room 414.

exceeded acceptable limits on 68 of the 71 days (96% of the time). Levels considered clearly dangerous to the collection have been reached and maintained for the last 26 days of the study (representing 37% of the study period).

Two 4th floor storage areas have been closely monitored for 14 days. The first (Figure 6), Art Storage (Room 419) demonstrates daily temperature fluctuations of 2 to 4°F (range of 64 to 70°F, for a total 2 week range of 6°F). This demonstrates that the temperature in this sensitive area is being insufficiently controlled on a daily basis. The humidity, however, presents the most serious problem. The humidity tends to show daily variations of about 7% and levels of up to 76% RH (the RH increased to 92% on June 1-2 from 10PM to 1AM when the air handler was inoperable because of a power outage). These conditions are exposing the collections to clear danger. Not only are the fluctuations likely to damage the paintings through shrinking and swelling, but the high humidity and dark conditions are condusive to mold growth on the canvas.

The second area (Figure 7) is Textile Storage in Room 421. The temperature again shows daily variation of ±5°F and a range from 67 to 72°F. Although this is within acceptable limits, the daily variation should be of considerable concern, since it suggests that the HACV system is having difficulty maintaining a uniform temperature, even prior to the most severe summer weather. Relative humidity levels range from 60 to 80%, with daily variation of at least 10% (and in one case 20%). These levels are of considerable concern since they promote the deterioration of the fabrics, affect the dyes, and encourage mold growth.

Other areas of particular concern include Room 402, Changing Exhibits, where levels of humidity of up to 77.4% RH have been recorded and Room 414, Military Collections, where 70.2% RH has been recorded. In addition, the Multipurpose Room and Auditorium have had levels of up to 76.4% RH.

These trends clearly indicate that the HACV system is failing to maintain the Museum collections within recognized standards. The temperature, while of secondary concern, exhibits daily variation in excess of acceptable limits over most of the storage areas. The humidity, of greatest concern, is uniformly too high and in many cases is within a danger zone requiring immediate attention and correction. The humidity within the Museum is affected not only by the air being distributed by the HACV system, but also by the moisture content of the structural elements. Because of the thick, porous walls and the wood construction, the Museum building has stored up, within itself, a large quantity of moisture. As a consequence, immediate reduction of the RH levels by the HACV system would still yield high levels since moisture would be drawn out of the structural elements for several months. In spite of this, levels throughout the building are too high and should quickly begin to be adjusted downward. The various readings suggest that while there is some control over the building

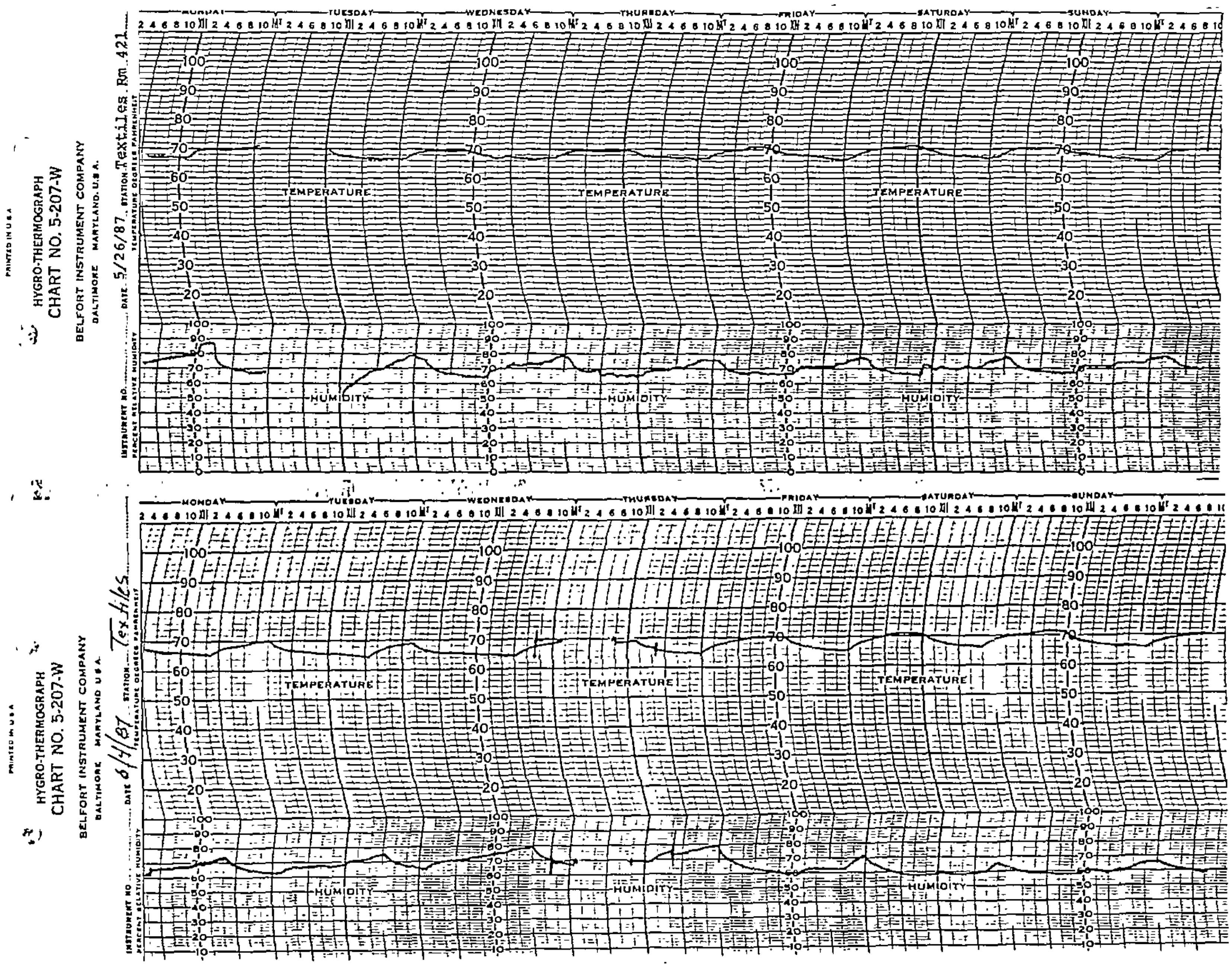

Figure 6. 14-day chart of Art Storage, Room 419 (5/26-6/8/87).

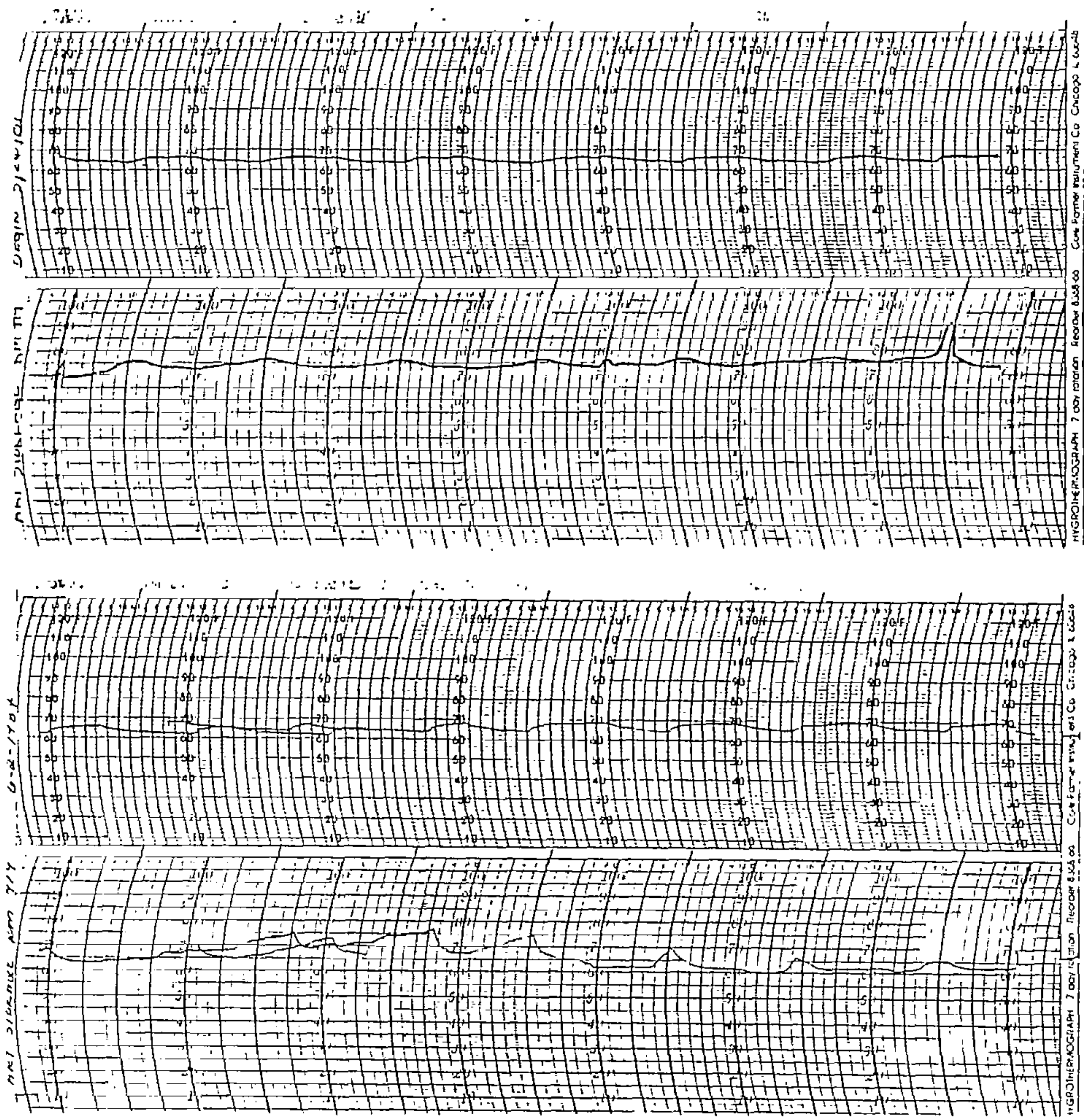

Figure 7. 14-day chart of Textile Storage, Room 421 (5/26-6/2/87, 6/4-6/10/87

conditions, the dehumidification is not sufficient to handle the load placed on it.

Possible Solutions and Recommendations

The complexity of this problem cannot be overstated. The control of temperature and humidity is the single greatest agency for the preservation of museum collections (Buck 1964:57; Thomson 1986:105), but central units require the attention of a qualified engineer, not technicians, conservation staff, or custodial personnel (Thomson 1986:105). With no disrespect intended, both GSA and the HACV contractors have vested interests which are not the same as those of the Musuem. The first recommendation, then, is for the Museum to make the hiring of a building engineer (not simply a head custodian), with adequate training and experience in operating HACV systems, a first order priority. It may take a year to stabilize the HACV system so it is imprudent to wait until the Museum is about to open to fill this position. If it is not possible to hire a building engineer in the near future, it is recommended that the Museum obtain an outside HACV engineer on a consultant basis to come in and completely examine the system and advise the Museum on operation options. This individual should protect the Museum's interests, and the consultation would involve examining not only the humidity problems, but also outlining necessary changes in air return vent sizes, establishing a periodic maintanence program, adjusting and calibrating zone controls, examining filtration efficiency, and so forth. It is estimated that the initial consultation would cost about $5000.

Other recommendations are secondary to this first recommendation and are offered as temporary measures until a qualified HACV engineer can assume responsibility for the oversight of the Museum's system.

1. There does not seem to be adequate reheat temperature to stabilize the humidity control. The reheat coils, while warm, do not appear to contain water over 100-110°F. Reheat temperatures of 140 to 160°F are needed for the system to operate efficiently, according to Mr. Hana. It is possible that the boiler in the physical plant is not being fired, or that it has been set very low by GSA to reduce energy costs. Raising this water temperature to 160°F may serve to reduce humidity levels and should be explored.

2. Dehumidification of individual rooms is possible, but should be considered a temporary measure until the central unit is made to function properly. As an example, a room 30 by 40 by 15 feet (such as Room 414, which requires a low humidity), contains about $500 m^3$. To lower the RH from 70% to 50%, while maintaining a temperature of 68°F, will require the removal of about 4 g of moisture per m^3, or a total of about 8 l (17 pints) per 24 hours (assuming a complete air change every 6 hours). Small commercial units are available for about $300 which will remove up to 41 pints per 24 hours (Grangers 3H324). In this particular situation it

might be possible to discharge water into what appears to be a condensate tube in the southwest corner of the room. Elsewhere lines could be gravity fed to the outside roll up doors.

3. It is not reasonable, however, to reduce the humidity levels by increasing the temperature and the Museum should resist such suggestions. Using the same room as above as an example, to lower the 70% RH to 50% RH would require raising the temperature from 68°F to 81°F, an unacceptable level for both human comfort and the stability of the collections.

Summary

It has been shown that the daily variation of temperature in the Museum storage areas is greater than desired for safe museum conditions, although for the most part the temperatures are at acceptable levels. The humidity, however, exhibits wide daily fluctuations and levels which are uniformly too high. The RH levels encountered in storage areas will tend to promote the corrosion of metal, the deterioration of organic materials, and the growth of mold. Elsewhere in the Museum the RH levels, while perhaps acceptable in rent generating commercial buildings, will lead to mold growth and extensive maintenance costs. In several rooms there is already a faint, but distinct, odor of mildew.

This situation has been of concern for the past four months, but the severity has dramatically increased since early May. The increased problem is correlated with Columbia's seasonal change. Beginning in May the RH begins to increase, peaking in August. There is a gradual decline in RH levels beginning in September. As a result, the current problem with humidity is expected to get worse if immediate steps are not taken.

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