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# Demonstration of Dehumidification Technology for a Missile-Storage Facility

**Final Report on Project F11-AR25**

Michael K. McInerney, Steven C. Sweeney, and Orange S. Marshall

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Final report



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Under Project F11-AR25, “Dehumidification of Forward Position Facilities for Munitions Storage in Okinawa”

# Abstract

Department of Defense (DoD) missile system components are vulnerable to corrosion damage that can hinder their mission-readiness and reliability. One 2005 study indicates that the cost of corrective and preventive corrosion maintenance for missile systems ranges from 5% to 20% of total maintenance costs. The study documented in this report demonstrated and validated the use of dehumidification technology to mitigate corrosion-related missile degradation. An Army demonstration site at Okinawa, Japan, was selected as representing a corrosion worst-case scenario, where the climate is hot and humid most of the year. The objective was to install a dehumidification system at an unconditioned, ventilated missile-storage facility to determine whether it could effectively reduce indoor humidity relative to outdoor ambient humidity. The principal metric was to maintain the building's interior RH at no more than 10% above the upper limit specified for inside the stored missile canisters, which would increase the service life of the canister desiccant and reduce the cost of corrosion-driven corrective missile maintenance.

Performance analysis of the demonstrated dehumidification system showed a 20% reduction in relative humidity compared to outdoor ambient levels. This demonstration project has a projected ROI of 5.12. Observations of operation and lessons learned are discussed.

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# Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Prevention and Control Project F11-AR25, “Dehumidification of Forward Position Facilities for Munitions Storage in Okinawa.” The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM) and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Richard J. Frey (OUSD(A&S), Materiel Readiness, Corrosion Policy and Oversight), Ismael Melendez (IMPW-E), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Materials and Structures Branch of the Facilities Division (CEERD-CFM), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). The ERDC-CERL project manager was Steven C. Sweeney. Significant portions of this work were performed by Mandaree Enterprise Corporation, LLC, Warner Robins, GA. At the time this report was published, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF; and Michael K. McInerney was the ERDC CPC Program Coordinator. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Lance D. Hansen.

Contributions to this project by Henry Nwe, Japan Garrison Directorate of Public Works, are gratefully acknowledged. Special appreciation is owed to Scott R. Hodgen, RDMR-WDP-MA, a contractor with the U.S. Army Aviation and Missile Command (AMCOM) Corrosion Program Office, Redstone Arsenal, AL. Mr. Hodgen provided key subject-matter expertise about desiccant materials that was directly incorporated into the metrics for evaluating the success of this demonstration project. The contributions of the subcontractor, American Engineering (NSK), are also acknowledged.

The Commander of ERDC was COL Ivan P. Beckman and the Director was Dr. David W. Pittman.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet | 0.02831685 | cubic meters |
| degrees Fahrenheit (°F) | (F-32)/1.8 | degrees Celsius |
| inches | 2.54 | centimeters |
| miles per hour | 0.44704 | meters per second |
| pounds (mass) | 0.45359237 | kilograms |
| yards (yd) | 0.9144 | meters (m) |

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# 1 Introduction

## 1.1 Problem statement

Like many other weapons systems, missile system components are vulnerable to corrosion damage that can interfere with their readiness and reliability. A cost-of-corrosion study sponsored by the Office of the Secretary of Defense (OSD) Corrosion Prevention Office (CPO) estimated that the U.S. Army Missile Command (AMCOM) spent approximately $1.6 billion in 2005 for corrosion maintenance, with more money spent on corrective maintenance than preventive maintenance on weapons systems (Herzberg et al. 2007). The cost of maintenance due to corrosion for missile systems ranged from roughly 5% to 20% of the total cost of maintenance for the missile systems studied. Some examples cited in Herzberg et al. (2007) include the following:

- Launcher, Tubular, Guided Missile, 19.4% of total maintenance cost
- Patriot Advanced Capability (PAC-1) Launcher Station, 5.5% of total maintenance cost
- Launcher, guided missile, aircraft, 15.3% of maintenance cost.

A major corrosion issue involved the need to ship 12 Patriot launchers in South Korea back to the United States for corrosion-related overhaul and repair at a cost of $4 million. In 2005, AMCOM spent $17.4 million for corrosion maintenance on Patriot systems alone, putting it in the AMCOM top 10 for average corrosion cost and in the AMCOM top 20 for total corrosion cost (Hawkins 2012).

The 1-1 Air Defense Artillery (ADA) Battalion stores Patriot missiles at Kadena Air Base in Okinawa, Japan. The climate at Okinawa is warm and humid all year, with a rainy season extending from approximately early May through late June. Typhoons occur during September and October, some with winds that reach 140 mph and drive water into utility buildings. During winter, the average temperature range is 58–68 °F, and during summer it is 80–89 °F. Warmer air holds more water vapor than cooler temperatures, so ambient moisture content ranges from high to extreme during most of the year.

Each Patriot missile at Kadena Air Base is stored in a humidity-controlled canister equipped with gaskets, desiccant, and humidity indicators. If the canister humidity exceeds an operations-specified value for an extended period, the excess humidity can render the missile non-mission capable (NMC). When a missile is in NMC status, it must be returned to a depot for overhaul, repair, maintenance, and recertification.

Specifications require that desiccant in Patriot missile storage canisters be replaced when the interior relative humidity (RH) reaches 30%, but in some cases at this Kadena facility canister interior RH has been found to exceed 40%. When it becomes necessary to replace the desiccant, the canister gasket also must be replaced as a precaution against mechanical damage that may render it ineffective for reuse. Due to high humidity at the subject location, maintaining the missile canisters in a mission-ready status results in unacceptably high costs, in terms of both materials and labor costs.

The U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) is updating storage humidity guidance that will raise the upper limit inside canisters to between 40 and 45% RH*. Even with this relaxation of the upper RH limit for the canister interior, however, missiles stored in hot and humid locations such as Kadena will still require more frequent changing of the desiccant than is necessary at other locations.

Reducing the humidity differential between a storage facility interior and the inside of a missile canister is a straightforward and highly effective idea for reducing the costs of canister and missile maintenance while effectively protecting missiles from corrosion damage. This report describes a demonstration/validation project, executed with funding from the DoD Corrosion Prevention and Control Program, in which a dehumidification (DH) system was installed at a Kadena missile-storage facility.

## 1.2 Objective

The objective of the work was to design and install a dehumidification system for a munitions-storage building at Kadena Air Base, Okinawa, that

* Scott R. Hodgen, RDMR-WDP-MA, U.S. Army Aviation and Missile Command (AMCOM) Corrosion Program Office, Redstone Arsenal, AL. Telephone conversation with Michael K. McInerney, 23 May 2018.

was neither designed nor constructed for conditioned air. The performance goal for the system was to maintain the building's interior RH at no more than 10% above the upper limit specified for inside the missile-storage canisters.

## 1.3 Approach

The missile-storage facility (MSF) used as the Kadena test location is a conventional concrete-frame, block-infill warehouse (Figure 1). The building has no climate control except for wall vents and wind-driven roof vents. Leaks in the roof allow moisture to infiltrate and aggravate the high-humidity indoor environment.

Figure 1. Storage facility used for demonstration/validation project.

Based on the initial onsite inspection of the candidate facility, the project specifications were developed. Site requirements were evaluated, including building and envelope repair needs, electrical requirements, and DH system layout. Final project requirements were developed and the DH system was installed and commissioned. Humidity and temperature sensors were installed on the facility's front and back interior walls to monitor system performance.

## 1.4 Metrics

The metric for success in this project was developed in collaboration with Kadena onsite experts. It was determined that the installed DH system should limit interior facility RH to no more than approximately 10% above the AMRDEC-recommended upper limit for RH inside the missile canisters. Specifically, the metric for the system was to maintain the RH at approximately 55% (±10%) inside the facility at a nominal indoor air temperature of 79 °F (±1.5 °F).

# 2 Technical Investigation

## 2.1 Project overview

There are two common types of DH technology: mechanical refrigeration and desiccant. There are two ways to supply air to dehumidifiers: (1) open cycle, which continually takes in and dries fresh air from the outside; and (2) closed cycle, which continually recirculates the indoor air. In a setting where there may be outgassing of propellants or other potentially hazardous materials inside the facility, a closed-cycle system tends to concentrate the gasses.

### 2.1.1 Desiccant DH systems

A desiccant system uses a highly efficient humidity-absorbing material called a desiccant, which draws moisture from humid air it is exposed to. When desiccant becomes too saturated to absorb any more water, it is recharged (i.e., dried) by moving it to a different location and exposing it to heat. Desiccant-type systems are well suited for reducing high humidity levels at lower temperatures. Industrial desiccant applications can reduce RH levels to below 35%.

Desiccant dehumidifiers are often lighter and quieter than comparable refrigeration-type dehumidifiers because they do not require motor-driven compressors, condenser coils, or chemical refrigerants. The design of a refrigeration-type DH system is also limited in the amount of moisture such systems can remove because their ability to remove heat from the source air is limited. (Air cooling is the mechanism by which water is condensed out of humid air.) Desiccant dehumidifiers, however, can operate effectively at lower temperatures because, within limits, they absorb moisture irrespective of the source air temperature.

### 2.1.2 Mechanical refrigeration DH systems

Mechanical refrigeration dehumidifiers are the most common type available. They typically function by using a fan to draw moist air over a refrigerated coil. The cold evaporator coil of the refrigeration device condenses the water vapor into liquid water and drains it from the system. Then a condenser coil reheats the dehumidified air and releases it back into the conditioned space. This technology works most effectively at higher ambient temperatures with a high dew point temperature (i.e., high humidity). In cold locations, however, refrigeration-type DH systems become less effective. They are most effective at over 45% RH, but can dehumidify cooler air when the RH exceeds 45%.

#### 2.1.3 Selected design

An open-cycle refrigeration-type system was selected for the demonstration. The general requirements are listed below:

1. The system must be a dedicated outdoor-air system incorporating a direct-expansion (DX) cooling system and reheat capability. The power requirement cannot exceed 240 V, three-phase alternating current (AC) service.
2. Systems that recirculate conditioned indoor air are not suitable for the application. The design must incorporate a makeup-air system that dehumidifies and reheats an exterior air supply to avoid the potential problem of concentrating explosive or hazardous gases inside the building.
3. The system must provide sufficient flow capacity to satisfy the greater of the ventilation requirements of ASHRAE 62.1-2007, Table 6-1, for warehouse applications; or the volume of outdoor air necessary to maintain a slight positive interior pressurization with all doors closed.
4. It must provide sufficient capacity to remove moisture from the incoming air to achieve an indoor RH level of 55%, ±10%. This requirement is based on the 1% occurrence of humidity ratio (HR) and mean coincident dry bulb temperature for Kadena Air Base.
5. The system must be capable of maintaining a consistent indoor air temperature of 79 °F ±1.5 °F throughout the year in order to reduce overall energy consumption while maintaining relative humidity within the specified range.

The unit selected for installation was a 9,200 cubic feet per minute (cfm) heating, ventilation, and cooling (HVAC) system manufactured by AAON Heating and Cooling Products (Tulsa, OK), shown in Figure 2. Specifications for the unit are available in Appendix A.

Figure 2. Selected dehumidification unit on concrete pad.

## 2.2 Installation

### 2.2.1 Power supply

System design required that three-phase power be routed to the building from the closest source, which was approximately 330 yards away. This line was extended to a pole across the street from the building. A three-phase 112.5 kilovolt-ampere (KVA), 1300 V Delta 208/120 V wye transformer was mounted to a concrete pad adjacent to the building (Figure 3). A standalone 400A/3/350A fused-disconnect switch junction box was installed between the transformer and the location for the DH unit (Figure 4).

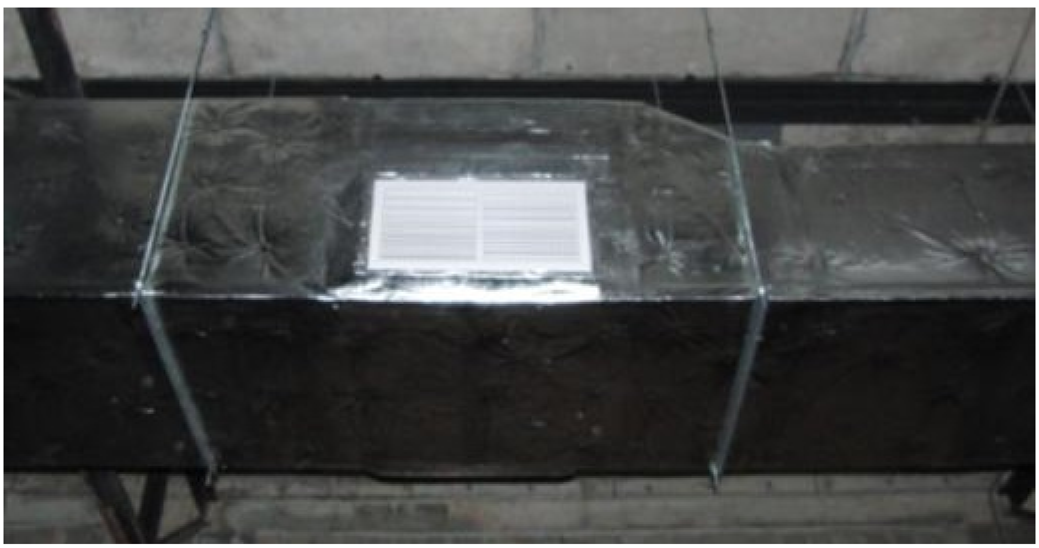
Figure 3. Transformer unit.

Figure 4. Disconnect switch.

### 2.2.2 HVAC unit

A 30,000 lb crane was used to lift and place the HVAC curb adapter and HVAC unit onto the concrete pad. Stainless steel ducting measuring 36 x 30 in. was fabricated and installed along the adjacent exterior wall of the MSF. A hole was cut in the block wall to transition the exterior ducting into the interior ducting. The ducting continues into the building at the same size, then progressively reduces in size to 36 x 22 in.; 28 x 22 in.; and 28 x 14 in. throughout the length of the building. Four 24 x 12 in. vents were mounted on each side of the ducting for a total of eight installed vents (Figure 5). Engineering drawings are reproduced in Appendix B.

Figure 5. Ducting vent showing left-to-right size transition from larger to smaller.



### 2.2.3 Building envelope upgrades

The original building had vents that had to be sealed. Covers shown in Figure 6 and Figure 7 were fabricated of galvanized steel to cover the 20 circular roof vents and 14 wall vents. The covers were painted gray to match the building interior. Foam insulation was installed on the inside of each cover to reduce heat transfer to the interior. The covers were fastened to the walls and ceiling using stainless steel concrete screws. A rubber strip was placed around the edges to seal the covers against the concrete.

Figure 6. Roof vent cover.

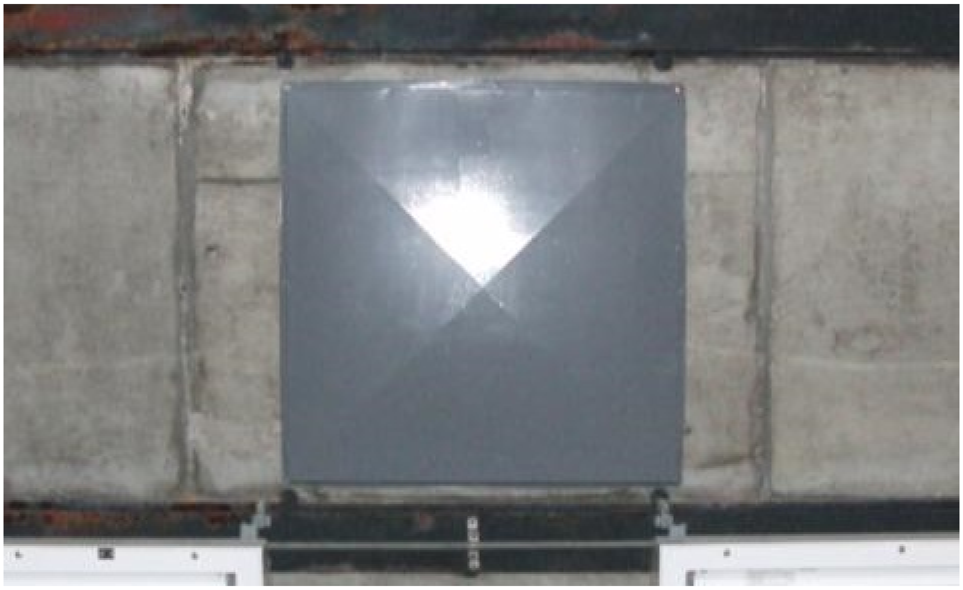
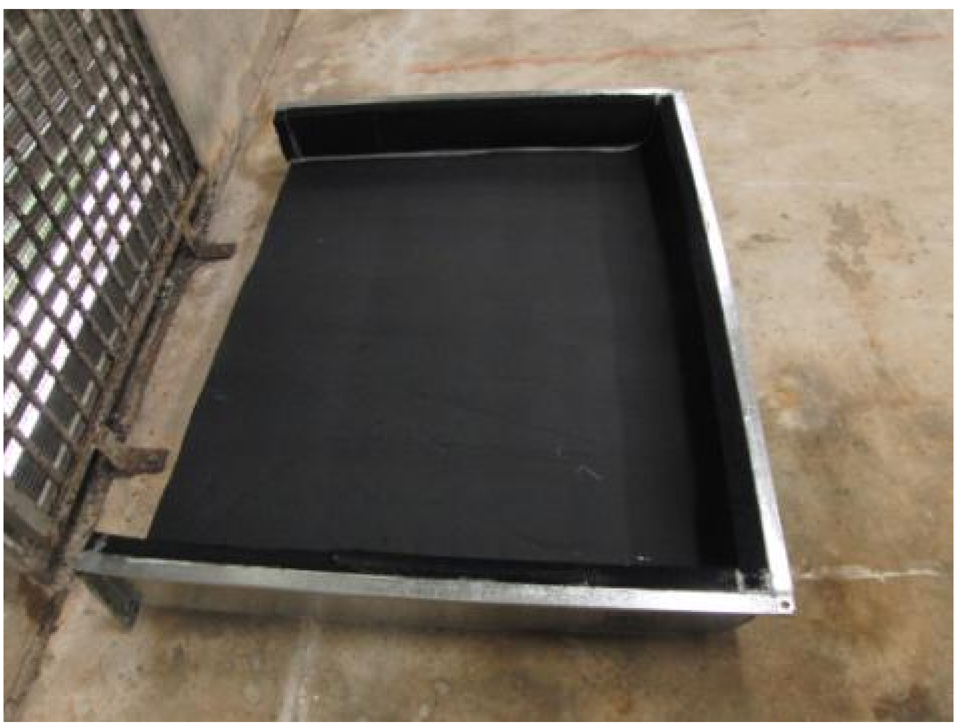


Figure 7. Wall vent cover with insulating foam.

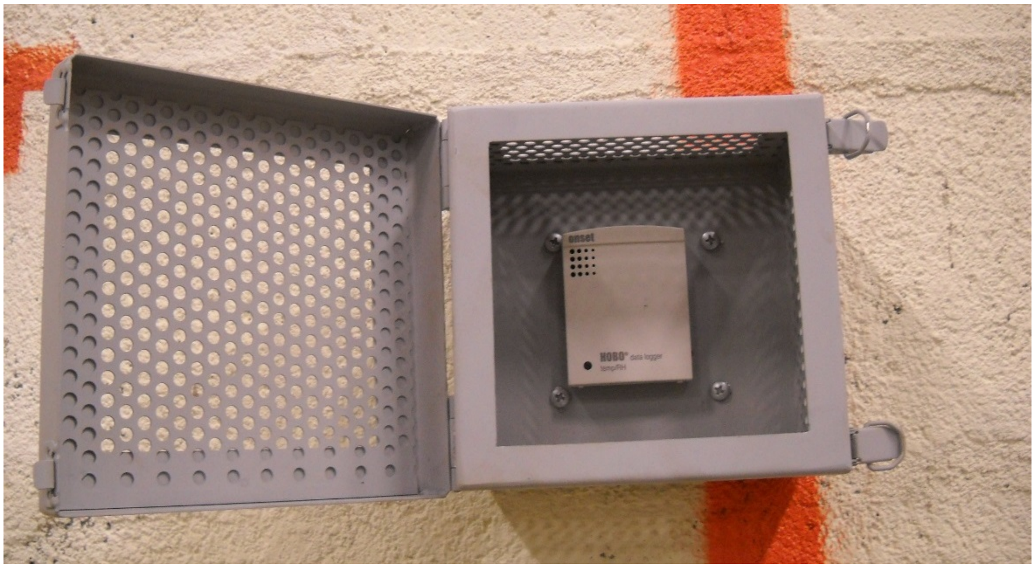


### 2.2.4 Sensors

Two HOBO® temperature and relative humidity sensors (Onset Computer Corporation, Bourne, MA), were each installed in a tamper-proof box. They were mounted on opposite walls—front and rear—inside the facility

(Figure 8). These units logged the data for later downloading to a computer at the end of the monitoring period.

Figure 8. Interior temperature and humidity sensor mounted in protective box.



## 2.3 Commissioning and monitoring

Startup of the makeup air unit (MAU) was delayed due to the manufacturer's misconfiguration of the fault/shutdown function of the supply-air fan's variable-frequency drive (VFD). This problem prevented manual reset the VFD to restore normal fan operation after a fault event. Manual reset functionality was restored by disabling the misconfigured component. Troubleshooting procedures determined that when each of the compressors was in operation, the associated condenser fan was not working because it had been wired to the wrong compressor. The manufacturer had reversed the condenser fan wiring, which caused high head pressure, shutdowns, and alarms. The fans were rewired to the correct compressors.

Additionally, it was determined that a wire was missing from the manufacturer-installed wire harness for the controls because the wrong harness had been used. A problem was resolved by adding a wire to the harness. The manufacturer-provided controller was also misconfigured, and was not showing proper displays. Following a reconfiguration of the controller, the unit was successfully started. No additional costs were incurred for these repairs because they were covered under warranty and contractor commissioning.

The DH unit was monitored for several weeks to ensure proper operation. After this verification period, control of the building and the equipment was transferred to the 1-1 ADA.

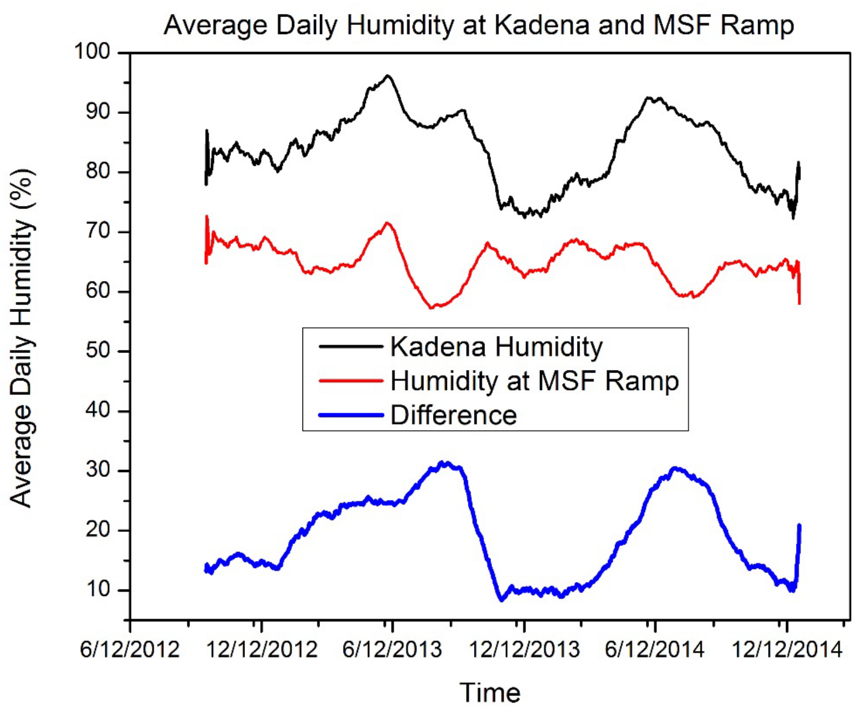
During the monitoring period, building interior temperature and humidity at the front (ramp) and rear of the facility were recorded hourly between 26 September 2012 and 29 December 2014. Area ambient temperature and humidity data sets covering the performance period were downloaded from Weather Underground (https://www.wunderground.com/), a web-based service that compiles and publishes global weather data. Location-specific outdoor weather data during the performance period were recorded at the Air Station at Kadena Air Base, Japan, for comparison and analysis.

# 3 Discussion

## 3.1 Results

Figure 9 shows the comparison of average daily outdoor humidity at Kadena* with data from the sensors mounted at the front (ramp) interior of the MSF. Figure 10 shows the comparison of the average daily outdoor humidity at Kadena and in the interior at the rear of the MSF. The graphs in Figure 9 and Figure 10 indicate that the DH system effectively reduced the facility RH by about 20% compared to the exterior RH. Note that the outdoor RH is typically very similar to the interior RH of the unmodified facility, which was ventilated only with unconditioned outdoor air before the DH system was installed.

Figure 9. Average daily outdoor humidity at Kadena and inside the MSF at front (ramp).




* Weather data documentation covering the duration of this project were obtained from Weather Underground website (see References). A representative 30-day data set for Kadena used in project data analysis is available for review at the following web page. Accessed 26 November 2018. https://www.wunderground.com/history/airport/RODN/2012/9/26/CustomHistory.html?dayend=29&monthend=12&yearend=2014&req_city=&req_state=&req_statename=&reqdb.zip=&reqdb.magic=&reqdb.wmo=.

Figure 10. Average daily outdoor humidity at Kadena and inside the MSF at the rear.

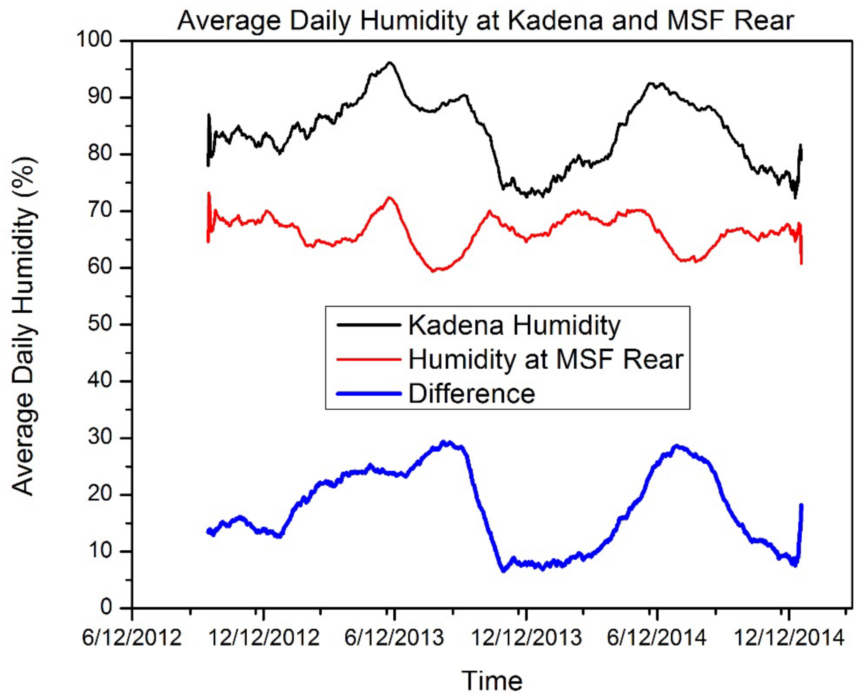



Figure 11 and Figure 12 show the daily maximum and minimum RH at the front and rear of the MSF, respectively. The data show that the DH system maintained the RH of both locations between about 45% and 90%. This result does not meet the target metric of controlling the RH at 55% ±10%.

The data show that the DH system was effective in reducing the RH inside the MSF by approximately 20% compared to the exterior RH. The outdoor RH averaged approximately 85% while the RH inside the MSF averaged approximately 65%. The system did not achieve the metric of sustaining interior RH at 55% ±10%. However, the 20% reduction in indoor RH has a positive effect in corrosion control. This result means there was 24% less moisture in the facility interior air, which translates to a 24% increase in the effective life of the canister desiccant. (This assumes that the amount of moisture migrating into the desiccant is proportional to the surrounding RH, so any reduction in facility RH will result in a corresponding increase in the time it takes for the desiccant to reach its equilibrium or saturation capacity.) As RH inside the MSF is reduced, less maintenance is required to sustain mission readiness of the missiles stored there. A 55% RH level would have reduced the moisture content by 35%, so the savings achieved in this demonstration represent about 70% of the savings initially targeted.

Figure 11. Maximum and minimum humidity at the front of the MSF (ramp).

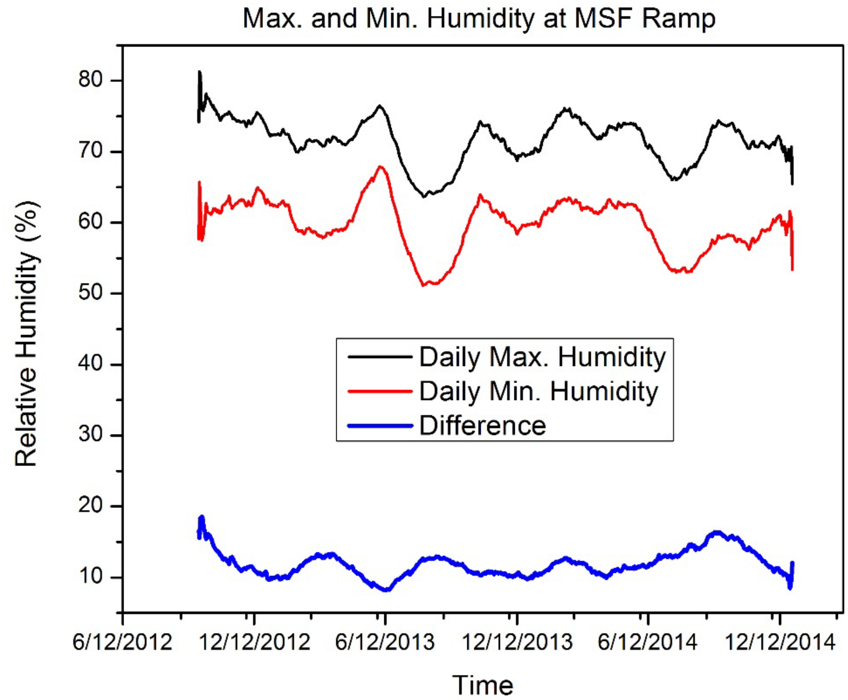
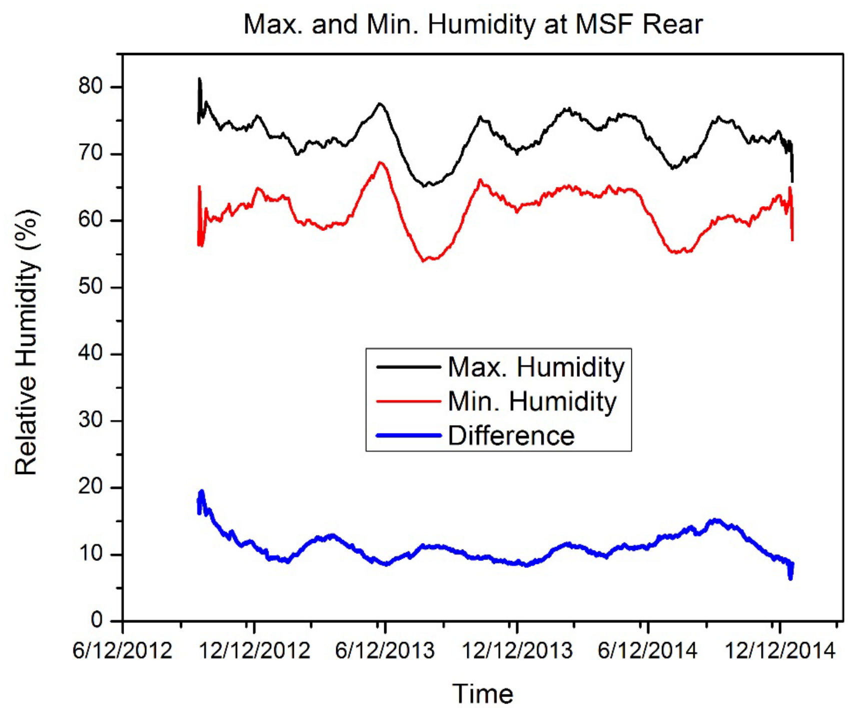



Figure 12. Maximum and minimum humidity at the rear of the MSF.



## 3.2 Lessons learned

Ultimately, the DH system did not provide the target range of dehumidification. Likely factors may include higher-than-expected air leakage in the building, decreased efficiency in the DH unit under the local operating conditions, or under-calculation of the unit capacity required to achieve the target humidity range.

Because of time constraints, the system designer was unable to visit the facility, but worked instead from the drawings and a report on then-current facility condition. Therefore, some design assumptions may not have been accurate enough for the project objectives, such as underestimation of the extreme heat and humidity at Kadena.

Even though the installation contractor sealed all the air vents, the project budget did not allow for better sealing of several roll-up doors. Insufficient sealing of these doors may have made it difficult to sustain positive air pressure inside the building, and the result of that condition would have been to leave the facility more ‘porous’ to the unwanted ingress of humid air. Also, any use of the doors as part of normal facility operations could allow rapid ingress of humid air, significantly reducing the effectiveness of the DH system on such occasions.

Because recirculation systems are not permitted in the type of facility used in this demonstration, building air leakage is one of the most important parameters for the system designer to know when executing similar future projects. In high-heat/high-humidity locations comparable to the test site, an air-leakage test should be performed prior to DH system design and retrofit for any building of this type.

# 4 Economic Summary

## 4.1 Costs and assumptions

Total project costs were $696,474. A rough breakdown of project expenses is presented in Table 1.

Table 1. Breakdown of total project costs.

| Description | Amount |
|---|---|
| Labor | $61,100 |
| Materials | $0 |
| Contracts | $606,198 |
| Travel | $17,176 |
| Reporting | $12,000 |
| Air Force and Navy participation | $0 |
| Total | $696,474 |

The field demonstration costs for this CPC project are shown in Table 2.

Table 2. Project field demonstration costs.

| Item | Description | Amount |
|---|---|---|
| 1 | Labor for project management and execution | $172,970 |
| 2 | Travel for project management | $51,525 |
| 3 | Dehumidification system design | $12,480 |
| 4 | Upgrade electrical service drop (convert to 3-phase) | $20,565 |
| 5 | Cost of dehumidification equipment and installation including ACCU, AHU, electric reheat, VFD, ductwork, insulation, piping, electrical, control, and miscellaneous | $221,675 |
| 6 | Cost of upgrading building electrical system including transformer (3-phase), cabling, conduit, panel boards, and miscellaneous | $90,375 |
| 7 | Cost of upgrading building, including installing new concrete pad, blocking off roof and wall vents, sealing openings, and miscellaneous | $126,884 |
| | Total | $696,474 |

In order to calculate a return on investment for this project, several assumptions have to be made about costs and benefits.

**Baseline scenario.** Baseline annual costs for a facility of the same storage capacity in the same climate are $170 K: $90,000 for desiccant replacement and $80,000 for gasket replacement.

New system cost is $429.5 K in Year 1, including DH equipment and installation for $385 K, electrical site improvements for $35 K, power costs of $9 K annually, and yearly maintenance and repair (M&R) of $500 per year, including new filters.

**Demonstrated technology.** New system cost for Years 2 through 22 is $9.5 K and includes power costs of $9 K annually, and yearly maintenance and repair (M&R) of $500 per year, including new filters.

Original assumptions were that new system benefits/savings are either $5 K or $755 K, based on the following factors: the cost of lost training due to M&R requirements would be $5,000 per year, and the cost of one missile being returned to the depot every 3 years for overhaul, repair, maintenance, and recertification would be $750,000. Due to the reduced effectiveness of the demonstrated DH system (as compared with the aspirational metrics), 70% of the original projected savings are now assumed to be $3.5 K and $525 K, respectively.

The system is assumed to have a functional life of 22 years.

## 4.2 Projected return on investment (ROI)

Based on the revised assumptions and costs presented in section 4.1, the return on investment was recalculated using the methods prescribed in OMB Circular A-94. For this project, the final calculated ROI is 5.12, as shown in Table 3.

Table 3. Projected ROI.

**Return on Investment Calculation**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Investment Required | | | | 697 |
| | | | Return on Investment Ratio | | 5.12 | Percent | 512% |
| | Net Present Value of Costs and Benefits/Savings | | | | 498 | 4,063 | 3,566 |
| A | B | C | D | E | F | G | H |
| Future Year | Baseline Costs | Baseline Benefits/Savings | New System Costs | New System Benefits/Savings | Present Value of Costs | Present Value of Savings | Total Present Value |
| 1 | 170 | | 429.5 | 528.5 | 401 | 653 | 251 |
| 2 | 170 | | 9.5 | 3.5 | 8 | 152 | 143 |
| 3 | 170 | | 9.5 | 3.5 | 8 | 142 | 134 |
| 4 | 170 | | 9.5 | 528.5 | 7 | 533 | 526 |
| 5 | 170 | | 9.5 | 3.5 | 7 | 124 | 117 |
| 6 | 170 | | 9.5 | 3.5 | 6 | 116 | 109 |
| 7 | 170 | | 9.5 | 528.5 | 6 | 435 | 429 |
| 8 | 170 | | 9.5 | 3.5 | 6 | 101 | 95 |
| 9 | 170 | | 9.5 | 3.5 | 5 | 94 | 89 |
| 10 | 170 | | 9.5 | 528.5 | 5 | 355 | 350 |
| 11 | 170 | | 9.5 | 3.5 | 5 | 82 | 78 |
| 12 | 170 | | 9.5 | 3.5 | 4 | 77 | 73 |
| 13 | 170 | | 9.5 | 528.5 | 4 | 290 | 286 |
| 14 | 170 | | 9.5 | 3.5 | 4 | 67 | 64 |
| 15 | 170 | | 9.5 | 3.5 | 3 | 63 | 59 |
| 16 | 170 | | 9.5 | 528.5 | 3 | 237 | 233 |
| 17 | 170 | | 9.5 | 3.5 | 3 | 55 | 52 |
| 18 | 170 | | 9.5 | 3.5 | 3 | 51 | 49 |
| 19 | 170 | | 9.5 | 528.5 | 3 | 193 | 191 |
| 20 | 170 | | 9.5 | 3.5 | 2 | 45 | 42 |
| 21 | 170 | | 9.5 | 3.5 | 2 | 42 | 40 |
| 22 | 170 | | 9.5 | 528.5 | 2 | 158 | 156 |

# 5 Conclusions and Recommendations

## 5.1 Conclusions

The installation of the HVAC unit for Building 43420 at Kadena Air Base in Okinawa, Japan, provided a more humidity-controlled environment for the 1-1 ADA Battalion's Patriot missile storage facility. The target interior RH of 55% ±10% was not reached at the high end of the range, but the RH reduction that was achieved should reduce the missile-maintenance requirement by extending the service life of canister desiccant and gaskets. This improvement is expected to reduce the occurrence of missiles falling out of mission-capable status due to corrosion damage. This ROI calculated for this demonstration project was 5.12.

## 5.2 Recommendations

### 5.2.1 Applicability

The wider use of dehumidification for storage of high-value supplies and equipment in facilities located in a humid, highly corrosive environment should be considered for purposes of sustaining readiness and reducing rehabilitation costs. UFC 4-420-01 addresses the use of dehumidification when specific criteria apply, but it does not specifically address what the criteria are. The results of this study show that the Army will reduce the corrosion-related maintenance and replacement costs of stored materiel, even in cases in which the materiel is stored in humidity-controlled canisters.

### 5.2.2 Implementation

DoD design criteria documents (Unified Facilities Criteria-Heating, Ventilating, and Air Conditioned Systems; UFC 3-410-01) should be modified to add a section in section 3–5 to allow for dehumidification in warehouses and other storage or maintenance where life-cycle cost analysis show that dehumidification can result in a high value rate of return due to savings in corrosion prevention and control. In addition, Department of the Army Technical Instructions (TI) 800-01, "Design Criteria," should incorporate similar considerations. Finally, UFC 4-420-01 should specifically state in section 2-4, Magazine Selection Considerations, that magazine structures intended to store materials packaged with desiccant humidity control should include a dehumidification system if the magazine interior relative humidity is expected to exceed the maximum allowable desiccant absorption capacity.

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# Appendix A: Dehumidification System Details

AAON®

## Unit Submittal

2425 South Yukon Ave · Tulsa, Oklahoma 74107-2728 · Ph. (918) 5832266 Fax (918) 5836094
AAONEcat32 Ver. 4.176 (SN: 6354490-UG3NR0YN)

RN-070-8-A-EA19-172:M000-U0B-DLG-B00-CHKDHBF-00-0000000AX

Tag: 9,200 CFM

| | | | |
|---|---|---|---|
| Job Name: | *Patriot Storage Facility-Naha, Japan* | Unit Submittal For: | |
| Job Number: | *Job #2253* | Unit Submittal Date: | *November 28, 2011* |

| | Base Option | Description |
|---|---|---|
| R | Series | Roof Top Unit |
| N | Generation | Ninth Generation |
| 070 | Unit Size | Seventy |
| 8 | Voltage | 208V/3Ø/60Hz |
| A | Interior Protection | Interior Corrosion Protection |
| E | Refrigerant Style | R-410A Variable Capacity Scroll Compressor (VCC) |
| A | Unit Configuration | Air-Cooled Cond. + Std Evap. Coil |
| 1 | Coil Coating | Polymer E-Coated Evap. and Cond. Coils |
| 9 | Cooling/Heat Pump Staging | Modulating - 2 VCC + 2 On/Off Comp. |
| 1 | Heating Type | Electric Heat |
| 7 | Heating Designation | Heat 7 - 60.1 kW |
| 2 | Heating Staging | 2 Stage |

| | Feature Option | Description |
|---|---|---|
| M | 1A. RA/OA Section | Motorized 100% Outside Air Dampers - No RA Opening |
| 0 | 1B. RA/EA Blower Configuration | Standard - None |
| 0 | 1C. RA/EA Blower | Standard - None |
| 0 | 1D. RA/EA Blower Motor | Standard - None |
| U | 2. OA Control | 2 Position Actuator |
| 0 | 3. Heat Options | Standard |
| B | 4. Maintenance Options | 115V Convenience Outlet - Factory Wired |
| D | 5A. SA Blower Configuration | 1 Blower + Premium Efficiency Motor + 1 VFD |
| L | 5B. SA Blower | 30" Direct Drive Backward Curved Plenum - 1600 rpm Max - Aluminum Wheel |
| G | 5C. SA Motor | 7.5 hp - 1760 rpm |
| B | 6A. Pre Filter Type | Metal Mesh OA Pre Filter |
| 0 | 6B. Unit Filter Type | 2" Pleated - 30% Eff |
| 0 | 6C. Filter Options | Standard |
| C | 7. Refrigeration Control | Fan Cycling |
| H | 8. Refrigeration Options | HGBPag + MHGR |
| K | 9. Refrigeration Accessories | ECM Condenser Fan - Head Pressure Control + Sight Glass |
| D | 10. Power Options | Power Switch - 400 amps |
| H | 11. Safety Options | Remote Safety Shutdown Terminals |
| B | 12. Controls | Phase & Brown Out Protection |
| F | 13. Special Controls | Make Up Air Unit Controller - CV Cool + CV Heat |
| 0 | 14A. Preheat Configuration | Standard - None |
| 0 | 14B. Preheat Sizing | Standard - None |
| 0 | 15. Glycol Percent | Water or No WSHP |
| 0 | 16. Interior Cabinet Options | Standard - Double Wall + R-13 Foam Insulation + Stainless Steel Drain Pan |
| 0 | 17. Exterior Cabinet Options | Standard |
| 0 | 18. Customer Code | Standard |
| 0 | 19. Code Options | Standard - ETL U.S.A. Listing |
| 0 | 20. Crating | Standard |
| 0 | 21. Water-Cooled Cond. | Standard - None |
| A | 22. Control Vendors | Wattmaster Controls |
| X | 23. Type | Special Price Authorization + AAON Gray Paint |

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# VCMX Components

AAON®

2425 South Yukon Ave · Tulsa, Oklahoma 74107-2728 · Ph. (918) 583-2266 Fax (918) 583-6094
AAONEcat32 Ver. 4.176 (SN: 6354490-UG3NROYN)

1A 1B 1C 1D 2 3 4 5A 5B 5C 6A 6B 6C 7 8 9 10 11 12 13 14A 14B 15 16 17 18 19 20 21 22 23

RN-070-8-A-EA19-172:M000-U0B-DLG-B00-CHKDHBF-00-0000000AX

Tag: 9,200 CFM

| | | | |
|---|---|---|---|
| Job Name: | *Patriot Storage Facility-Naha, Japan* | VCMX For: | |
| Job Number: | *Job #2253* | VCMX Date: | *November 28, 2011* |

**Hardware Included For VCMX Controller**

| Part # | Included Parts | Assigned Channel |
|---|---|---|
| V07150 | VCMX Controller with EBUS | |
| R28390 | Suction Pressure Transducer | MainController\AI5 |
| R82890 | Supply Air Temp Sensor - Field Installed | MainController\AI2 |
| R81550 | Outside Air Temp Sensor | MainController\AI4 |
| R69190 | VCMX Large Expansion Module | |
| P62520 | Proof of Flow Sensor | LargeExpansionModule\BI3 |
| R34700 | Outside Air Humidity Sensor | LargeExpansionModule\AI1 |
| R90230 | VCMX Head Pressure Module | |
| R22020 | Head Pressure Sensor | |
| R22020 | Head Pressure Sensor | |
| R22020 | Head Pressure Sensor | |
| R22020 | Head Pressure Sensor | |

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| VCMX Controller with EBUS | Analog In | | X | | X | X | | |
| | Analog Out | X | X | | | | | |
| | Binary In | | | | | | | |
| | Relay Out | X | X | X | X | X | | |
| | Digital Sensor(s) | | | | | | | |

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| VCMX Large Expansion Module | Analog In | X | | | | | | | |
| | Analog Out | | | X | | | | | |
| | Binary In | X | | X | | | | | |
| | Relay Out | X | | | | | | | |

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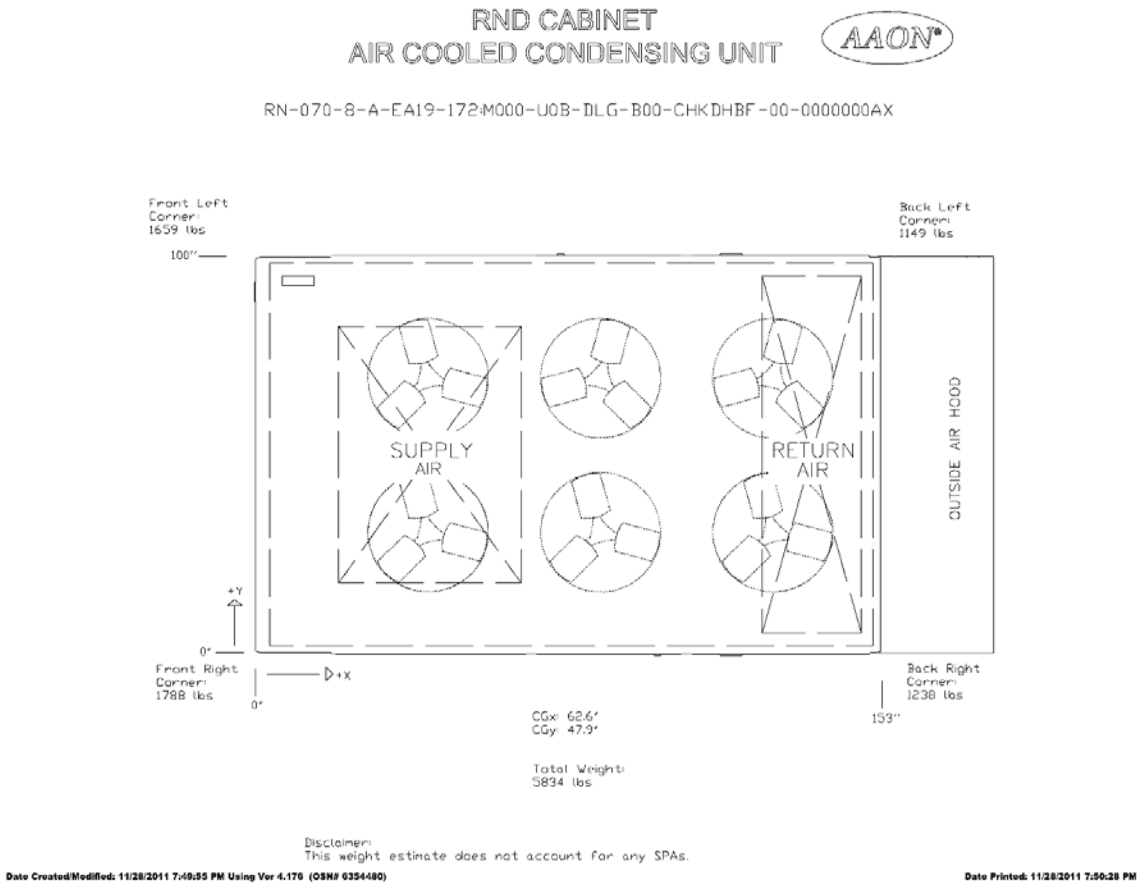
RND CABINET
AIR COOLED CONDENSING UNIT
AAON®
RN-070-8-A-EA19-172:M000-U0B-DLG-B00-CHKDHBF-00-0000000AX
Front Left Corner: 1659 lbs
Back Left Corner: 1149 lbs
100"
SUPPLY AIR
RETURN AIR
OUTSIDE AIR HOOD
+Y
0"
+X
Front Right Corner: 1788 lbs
Back Right Corner: 1238 lbs
0"
153"
CGx: 62.6"
CGy: 47.9"
Total Weight: 5834 lbs
Disclaimer:
This weight estimate does not account for any SPAs.
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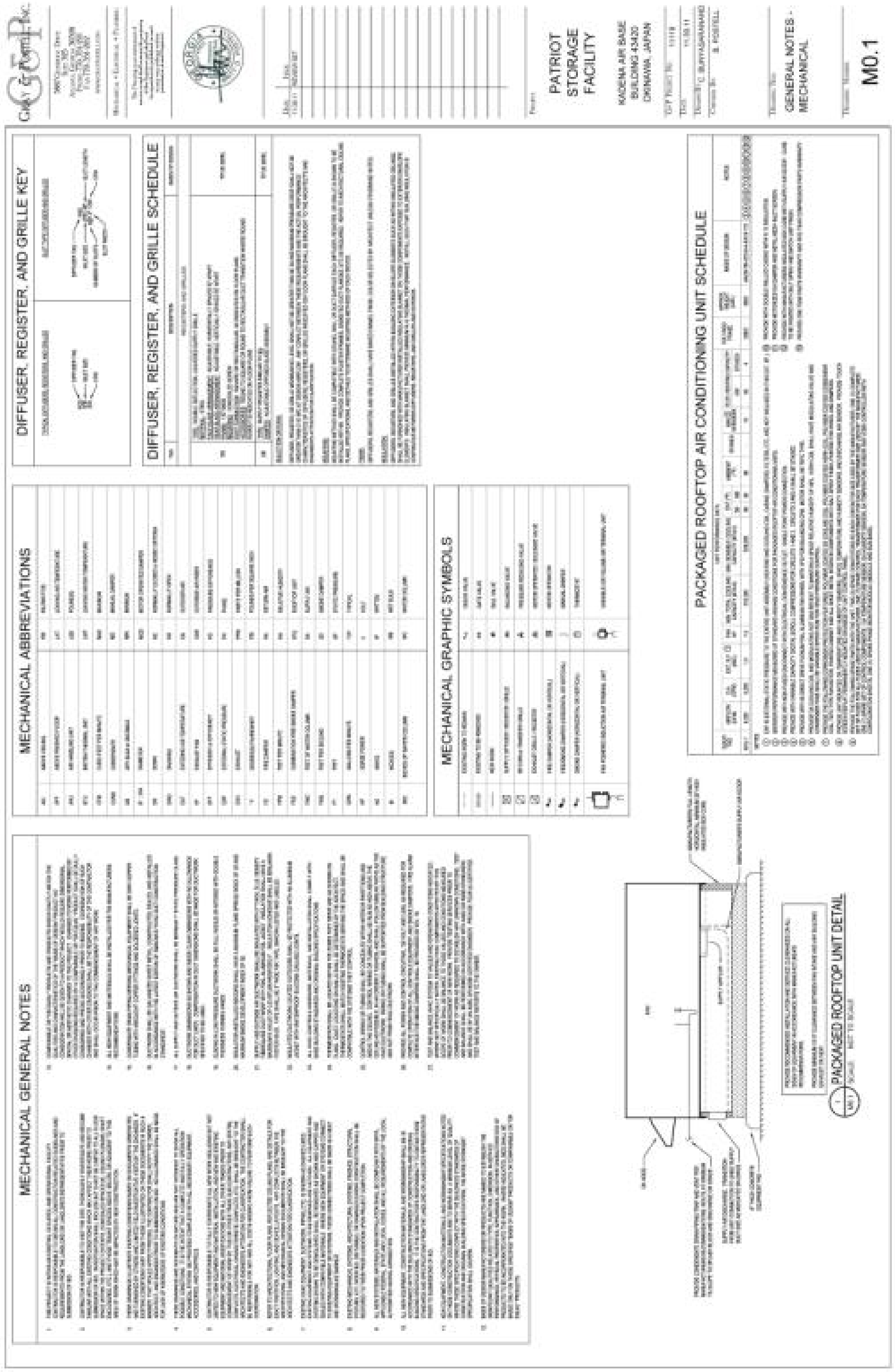
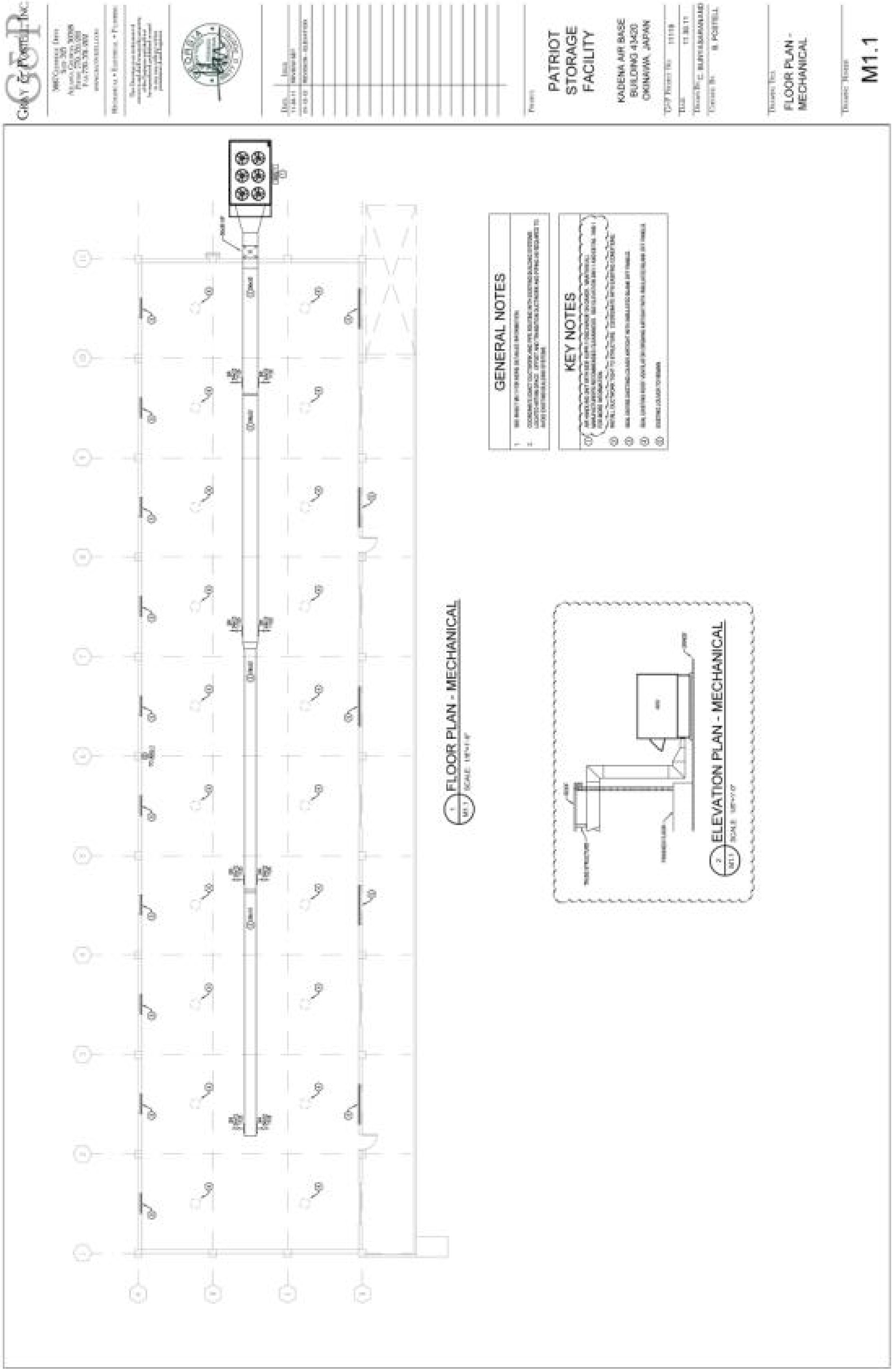
# Appendix B: Engineering Drawings

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KEY NOTES
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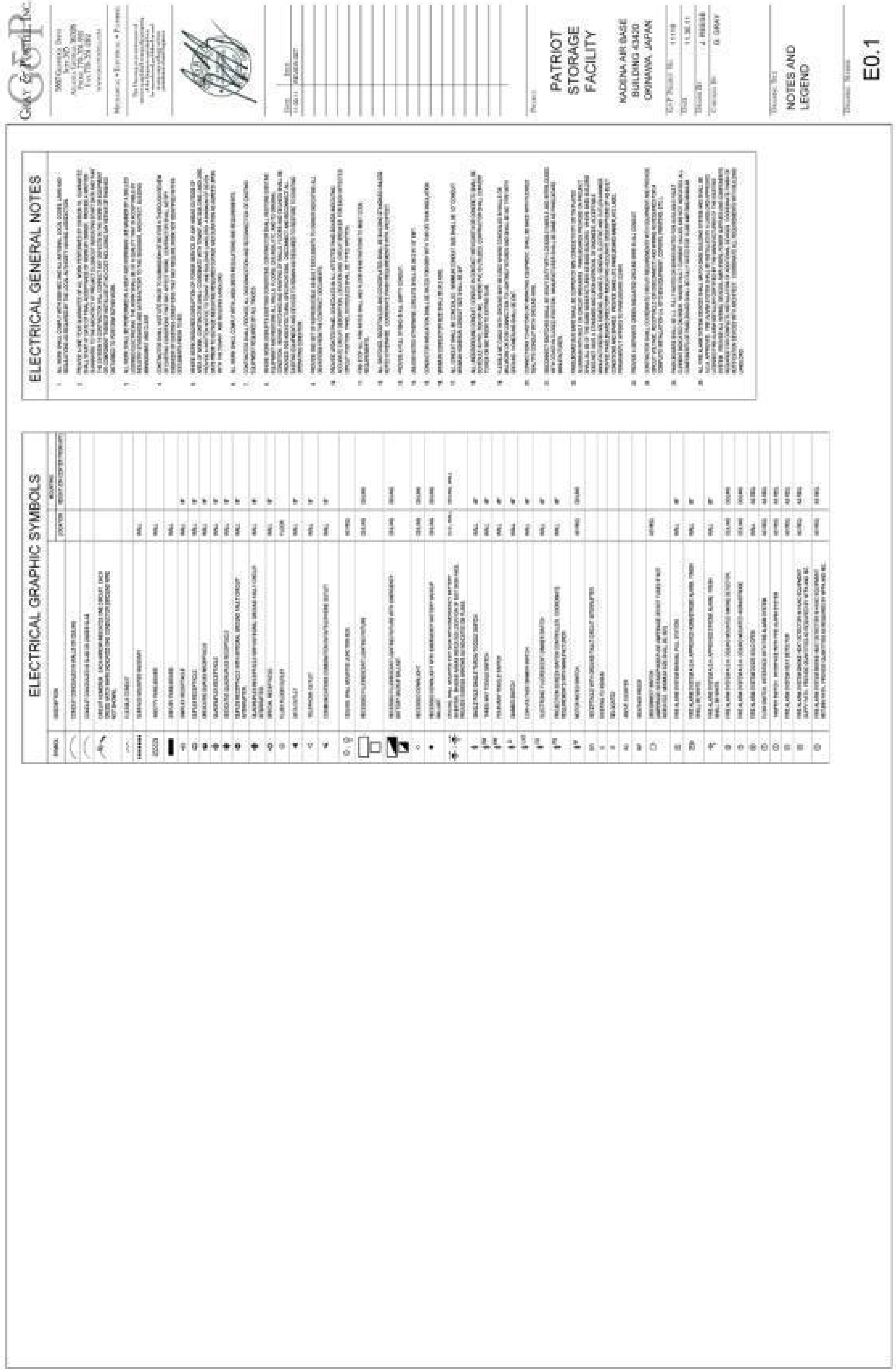
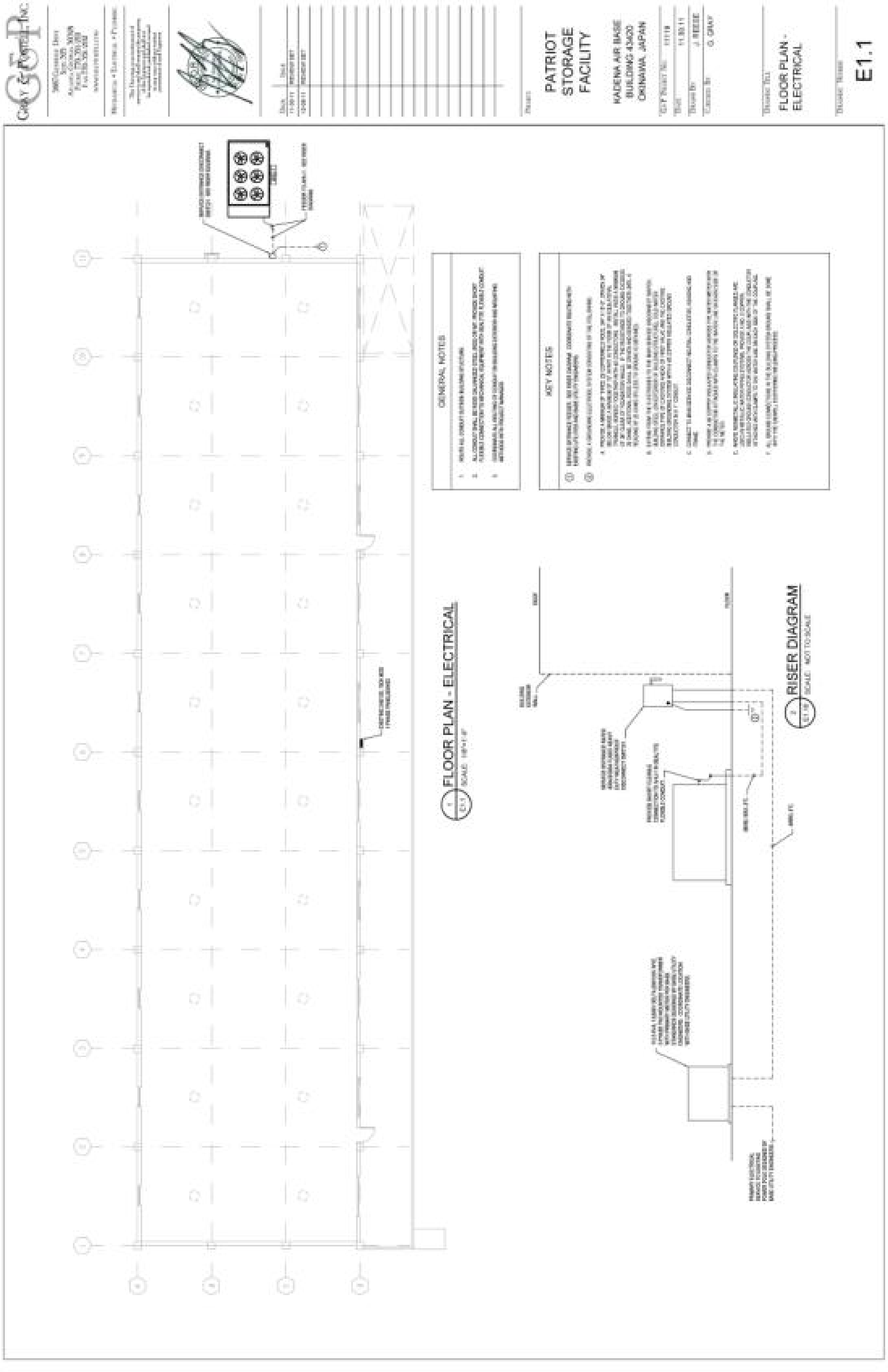
ELEVATION PLAN - MECHANICAL
PATRIOT
STORAGE
FACILITY
KADENA AIR BASE
BUILDING 43420
OKINAWA, JAPAN
FLOOR PLAN -
MECHANICAL
M1.1


ELECTRICAL GRAPHIC SYMBOLS
ELECTRICAL GENERAL NOTES
PATRIOT
STORAGE
FACILITY
KADENA AIR BASE
BUILDING 43420
OKINAWA, JAPAN
NOTES AND
LEGEND
E0.1


FLOOR PLAN - ELECTRICAL
GENERAL NOTES
KEY NOTES
RISER DIAGRAM
SCALE: NOT TO SCALE
PATRIOT
STORAGE
FACILITY
KADENA AIR BASE
BUILDING 43420
OKINAWA, JAPAN
FLOOR PLAN -
ELECTRICAL
E1.1

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**14. ABSTRACT**

Department of Defense (DoD) missile system components are vulnerable to corrosion damage that can hinder their mission-readiness and reliability. One 2005 study indicates that the cost of corrective and preventive corrosion maintenance for missile systems ranges from 5% to 20% of total maintenance costs. The study documented in this report demonstrated and validated the use of dehumidification technology to mitigate corrosion-related missile degradation. An Army demonstration site at Okinawa, Japan, was selected as representing a corrosion worst-case scenario, where the climate is hot and humid most of the year. The objective was to install a dehumidification system at an unconditioned, ventilated missile-storage facility to determine whether it could effectively reduce indoor humidity relative to outdoor ambient humidity. The principal metric was to maintain the building's interior RH at no more than 10% above the upper limit specified for inside the stored missile canisters, which would increase the service life of the canister desiccant and reduce the cost of corrosion-driven corrective missile maintenance.

Performance analysis of the demonstrated dehumidification system showed a 20% reduction in relative humidity compared to outdoor ambient levels. This demonstration project has a projected ROI of 5.12. Observations of operation and lessons learned are discussed.

**15. SUBJECT TERMS**

Warehouses; Guided missiles–Storage; Guided missiles–Corrosion; Humidity–Control; Dampness in buildings

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
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