Fort Sill Heating, Ventilation, and Air Conditioning (HVAC) Assessment

US Army Corps of Engineers
St. Louis District

Mandatory Center of Expertise for the Curation and Management of Archaeological Collections

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Fort Sill asked the U.S. Army Corps of Engineers, St. Louis District to assist them in their efforts to upgrade three buildings as part of the rehabilitation of portions of the Fort Sill Museum. St. Louis District personnel conducted a site visit to evaluate (1) the current heating, ventilation, and air conditioning (HVAC) systems and building structures for Buildings 438 and 442 and (2) the building structures for the addition of an HVAC system in Building 346. Planned building uses, including interpretive displays, collections storage, and closed exhibits, were considered in the evaluation of current and possible environmental-control systems. Recommendations, including cost estimates, on the best method for upgrading or replacing existing environmental-control systems and general advice for improving the efficiency of such systems are provided.

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1

Introduction

Problem

Fort Sill, as part of their ongoing effort to upgrade the museum, facilities, and archaeological and historical collections, is reviewing their existing heating, ventilation, and air conditioning (HVAC) systems in three buildings slated for rehabilitation. Existing HVAC systems are aged and have proved unreliable in providing temperature and humidity levels sufficient to protect museum collections.

The overall size, shape, and construction of the 1870s stone buildings, as well as the remnants of previous renovations, have contributed to the ineffectiveness of the current HVAC systems. Additionally, the variable climate of Oklahoma, often changing quite rapidly, is inherently challenging to any climate control system at Fort Sill. Museum staff are also confronted with a formidable task as they strive to strike a balance between providing adequate storage conditions for artifacts and providing tolerable working and visiting space in mixed-use buildings such as those planned for the Fort Sill Museum. The fragile nature of Fort Sill's museum collections, however, necessitates the installation of new HVAC systems capable of meeting these challenges.

Project Background

Fort Sill, recognizing the need for upgrading the failing HVAC systems, requested the U.S. Army Corps of Engineers, Mandatory Center of Expertise for the Curation and Management of Archaeological Collections (MCX-CMAC) to provide Fort Sill with an assessment of three buildings: two containing existing HVAC systems and one possessing no current HVAC system. As part of Fort Sill's museum plan, these three buildings will be rehabilitated to accommodate interpretive displays, collections storage, and closed exhibits. At Fort Sill's request, MCX-CMAC staff planned a site visit to assess the current HVAC systems and gather information regarding museum storage and planned-use areas. This information was used to produce this report, which offers recommendations on the best method for upgrading or replacing the existing climate control systems.

Climate and Collections

Since it is usually necessary to upgrade the HVAC systems of historic buildings during renovation, it is important to realize the affect that temperature and relative humidity have on historical collections. Changes in temperature and relative humidity, and exposure to light, dust, and pollution cause detrimental chemical and physical reactions in such objects. Therefore, the installation of a climate control system with not only reliable temperature control but also humidification and dehumidification capabilities is crucial for maintaining the fragile state of historical collections.

These collections, in the case of Fort Sill, include many leather, metal, organic, and textile artifacts. Artifacts such as these require a reliable and constant temperature and relative humidity level. Atmospheric moisture can contribute to corrosion of metals, the warping of wood, and mold growth, which can occur when the relative humidity level is above 65%. Excessive heat may cause certain materials to become brittle. Fluctuating temperature levels will result in expansion or contraction of metal causing cracking and buckling. Rapid temperature and relative humidity fluctuations every day over a period of time will cause serious deterioration in leather, wood, textiles, and other organics. As fluctuations occur, the absorption and releasing of moisture will cause subsequent swelling and shrinking of organic objects, leading to warping.

The buildings under assessment are used to store various types of artifacts and documentation, including books, photographs, maps, leather tack equipment, wooden carriage parts, plastic, metal, and various display materials. Future plans include retaining portions of the buildings for collections storage and adding interpretive and other museum displays. Each building will be accessed by the public and, in the case of Building 438, will be used for archival research by museum and volunteer staff and various interested researchers. These types of mixed-use buildings require a balanced climate control system. Composite materials, such as books, and photographs, among other things, require specialized temperature and humidity levels. However, staff, researchers, and public visitors must also be accommodated. Additionally, collections storage areas should be protected from the inherent climate fluctuations caused by the high-traffic public areas.

Temperature

Generally, the lower the temperature the better, because the rate of chemical reactions and biological activity decreases as the temperature decreases. Most chemical reactions will double in rate with each increase of 18°F (Applebaum 1991). High temperatures also cause an increase in biological activities such as mold growth and pest reproduction. Rapid fluctuations in temperature, as occurs when climate control systems are turned off and on, may cause the separation or splitting of objects made-up of different non-moisture absorbent materials having different expansion rates (National Park Service 1990). Because of the prevalence of composite artifacts (those artifacts containing a variety of materials, both organic and inorganic) in the Fort Sill collections, damage to the artifacts caused by rapid changes in temperatures is a real problem.

Relative Humidity

Water vapor plays a role in various chemical, physical, and biological forms of deterioration. The relation between temperature and the level of moisture in the air is referred to as the relative humidity (RH). Temperature determines how much moisture the air can hold. This linkage of moisture to temperature is crucial in understanding how climate affects museum collections. For example, wood will shrink from loss of moisture when the temperature is rising and the moisture content of the air remains the same. (National Park Service 1990)

Hygroscopic materials (wood, paper, leather, basketry, textiles, ivory, bone, and other organics) absorb or release moisture to the air. Since these materials contain water, the amount of the water they hold is determined by the relative humidity of the surrounding air. Relative humidity levels greatly affect museum collections, even more so than temperature, since temperature is important mostly in how it affects humidity. (National Park Service 1990)

High RH causes metals to corrode and increases the likelihood of infestations by biological agents. High relative humidity levels cause swelling and warping of wood and ivory; softening

and sticking of adhesives and sizing; and cockling of paper. Very low RH levels cause shrinkage, warping, and cracking of wood and ivory; embrittlement of paper and adhesives; tendering of textiles; and the desiccation of basketry. Again, the prevalence of these types of organic materials in Fort Sill's collections sets the stage for disastrous consequences if relative humidity levels (or temperature levels) are constantly fluctuating. (National Park Service 1990)

> Diurnal (24 hour) fluctuations cause the most serious deterioration. Changes in water content result in dimensional changes in hygroscopic materials. They swell or contract, constantly adjusting to the environment until the rate or magnitude of change is too great and deterioration occurs (National Park Service 1990: 4:13).

In addition,

> mechanical systems can create serious damage to collections by any sort of malfunction. Complete shut-off of a system, malfunction in a controlling sensor or switch, or any other malfunction, can cause rapid and extreme shifts in relative humidity, or rapid shifts in temperature that cause rapid shifts in relative humidity. If a humidification system that provides 45% relative humidity in a space that, without humidification, would be below 10%, a change of 35 percentage points could occur within hours. Any hygroscopic material not containerized, particularly painted wood, could sustain immediate damage (Appelbaum 1991: 37).

An example of a hygrothermograph chart from the *National Park Service Museum Handbook* (Figure 1) shows the effect on temperature and relative humidity levels when the furnace was turned off over a weekend. As a result, the relative humidity rose steadily over the course of the

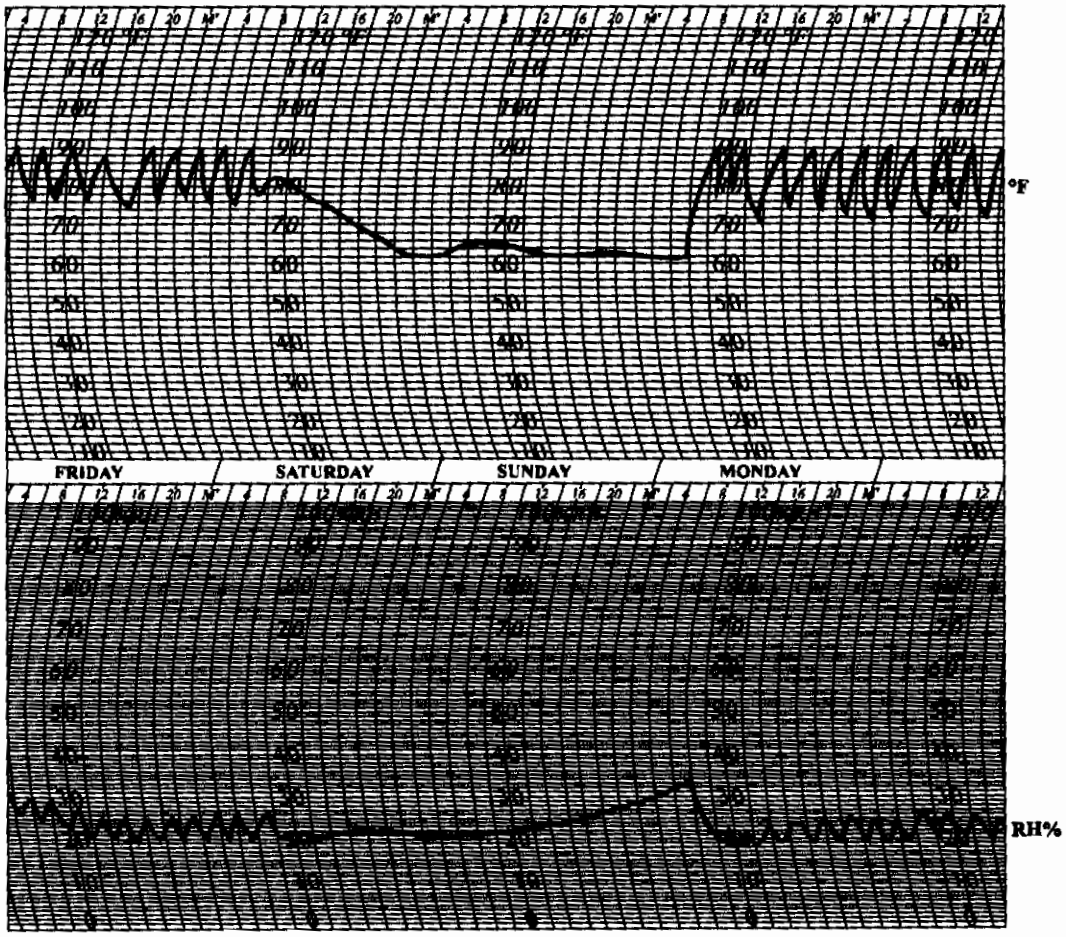

Figure 1. Hygrothermograph chart that illustrates the results of turning off the furnance (from National Park Servicce 1990).

weekend. Subsequently, during the following week, as the temperature rose, the relative humidity level remained low. The illustration shows that within a few hours on Monday, the relative humidity dropped 15% as the furnace reheated the room. As previously explained, this rapid relative humidity change is very damaging to any hygroscopic artifact.

Recommended Climate Ranges

The planned mixed use of the buildings and the often extreme Oklahoma weather changes make climate control a challenge at Fort Sill. A steady relative humidity every day and night of the year between 40 and 60% would be ideal for most collections. However, maintaining a 40% relative humidity rate in the summer would not be practicable for the local climate. A reasonable alternative would be to provide a steady relative humidity of about 35–40% in the winter, a steady 60% in the summer, and to adjust the levels between the two in the fall and spring, with daily fluctuations of no more than a few percent and monthly levels that change no more than 5% per month (Appelbaum 1991). Monitoring relative humidity and implementing improvements to stabilize the environment and avoid extremes is imperative to the success of this type of gradual climate adjustment. Additionally, adjustments in the climate control settings must be constantly made as the system is tested to produce the desired amount of variation.

Similarly, temperature levels can be set to drift between seasons gradually. Desirable temperature levels for mixed collections are usually around 68–70°F. Using these figures in the winter instead of a more common 75–80°F will help keep relative humidity levels from plunging. Setting wintertime temperatures in storage areas that are not often accessed by people in the low 60s is advantageous for the collections, and energy conservation. A gradual increase of temperature for the summer months, taking into account the effect that temperature has on relative humidity, can be performed with monitoring. (Applebaum 1991)

Like-material artifacts (such as all metal ammunition) can be stored in such a way as to take advantage of the zoning properties of the climate control system. Hence, temperature and humidity levels can be set to a more appropriate level for those materials. This can be useful for metal artifacts since metal is best stored in low RH (below 35%) environs. A portable dehumidifier, in conjunction with the HVAC system, may be useful in small rooms to keep the humidity levels low. Monitoring of the relative humidity can provide feedback on whether or not such a practice is successful.

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Results of Condition Assessment

During the period 2–4 September 1997, MCX-CMAC conducted a site visit to evaluate (1) the current HVAC systems and building structures for Buildings 438 and 442 and (2) the building structures, for the addition of an HVAC system in Building 346. The assessment was conducted with the assistance of Fort Sill personnel, Towana Spivey and Louis Vogele. Building plans are included as figures and show arbitrary room numbers/designations to aid in the assessment description.

Building 438—Old Child Care Facility

This stone building, most recently used as a child-care facility, is currently being used for archives storage, a library, and a soon-to-be art gallery. The existing climate control systems of Building 438 are antiquated and provide ineffective service to the building. The air-handling units seem to run excessively, while indoor temperatures are slow to reach desired levels. The existing thermostats are not controlled by building or Fort Sill personnel. Chilled and hot water supply pipes were leaking in the basement mechanical room. The air conditioning condensers are located near the south side of the building. Current plans call for a wood fence to screen these units.

The western portion of the building has recently been renovated for use as a fine art gallery. The library occupies the room to the east of the gallery. The entry/reception area occupies the eastern portion of the building. Archives, maps, and photographs storage are located in the southeast wing of the building. The basement is full height, with the dirt floor sloping from the west up to a crawl-space height at the eastern end of the building. The interior walls are painted plasterboard, all ceilings are suspended acoustical tile systems, and all floors are tiled except the art gallery, which is carpeted. All rooms have single-pane glass windows that can be equipped with storm windows if needed. Refer to Figure 2 for an illustration of the building floor plan.

Room 1 contains the new art gallery, which was recently renovated to include track lighting. Currently, two restrooms and a storage room occupy the west end of the room. Three large, central, overhead diffusers are present. This large room was noticeably cooler than the rest of the building, with a thermostat reading of 69° F.

Room 2 houses the library and contains four rows of books on metal shelving. Two large vents are overhead in the suspended ceiling. The high shelving in this room likely creates unmanageable microclimates throughout the room. The thermostat in this room read 72° F at the time of visit, and the vent emitted constant air.

Room 3 includes the adjacent office area, the main building entrance, a reception desk, an office, a break room, a restroom, and a mechanical room. This area was noticeably warmer than the library. A thermometer showed a temperature of 78° F and a hygrometer showed a humidity of 65%. One central, overhead vent services this room.

Room 4 is located to the south of the office/reception area and includes the archives room. This room contains filing cabinets and metal shelving along with perimeter of the room and map cases in the middle. Work tables also are present in the room. One central, overhead diffuser services this room. The documentation/map room was comparable in temperature and humidity to the office area.

Room 5 is the photographic storage room. Located south of the document/map room, Room 5 also contains filing cabinets and shelving along the wall, with map cases, shelves, and tables in

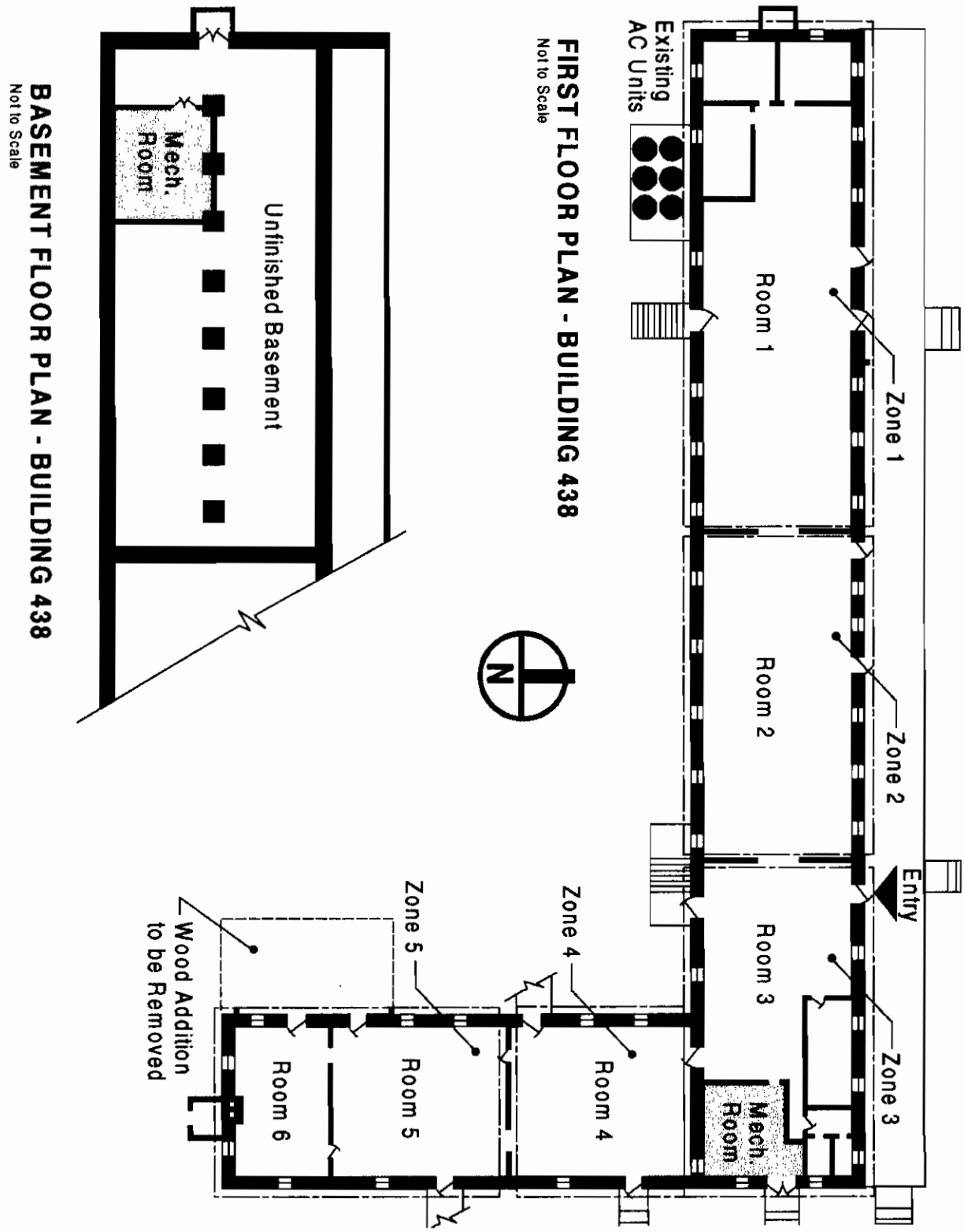

Figure 2. Existing conditions in Building 438.

the center of the room. One central, overhead diffuser services this room. The thermostat reading in this room was 74° F.

Room 6 is located to the south and consists of a laboratory/break room. Kitchen facilities were present along with laboratory equipment and some documentation storage. One central, overhead diffuser services this room. The thermostat reading in this room was 74° F. A small wooden addition is located directly west of Room 6. This addition is to be removed according to museum plans.

Building 346—Quartermaster Warehouse

This stone building, originally a quartermaster warehouse, has a partial basement and second floor (Figure 3). Currently, it is used for storage of wagon parts and other miscellaneous items. Plans include exhibiting wagon and transportation vehicles in half of the building (Room 1) and using the east side of the building for storage. No HVAC system currently exists in this building. As a result, the interior temperature at the time of assessment was 90°F.

Building 346 is currently only equipped with individual gas-fired heating units. As illustrated in Figure 3, overhead units are located in both the large eastern and western rooms (Room 1 and Room 5, respectively) of the building. A mixture of floor units provides heat to the central portion of the building. These units are old or antiquated; therefore, they provide only a basic level of climate control.

The stone building is fitted with single pane windows. The roof construction is a timber frame without insulation. Floors are cement, at places covered by vinyl tiles. Interior walls are stone or wood framed, covered with paneling. A second floor area occupies the central portion of the building. This second level is constructed with dimension lumber and is accessed by a steep wood staircase. The second level remains unfinished with dormer windows providing natural light.

The central portion of the building is partitioned into several rooms (Rooms 2, 3, and 4), including two restrooms. The main entrance into Building 346 is also located in this central portion. Currently used for miscellaneous storage, these rooms may provide small reception areas or offices when rehabilitated.

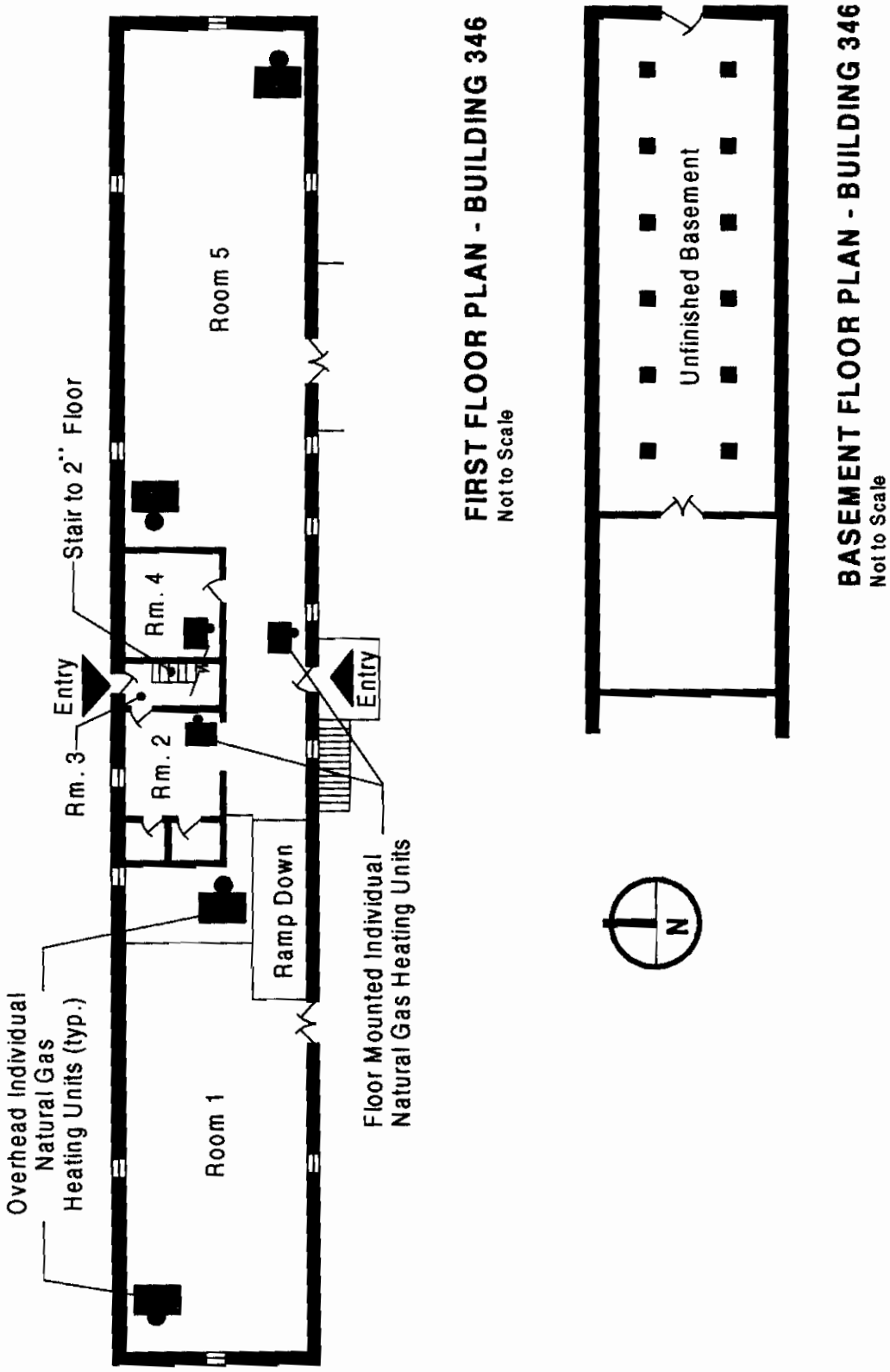

Figure 3. Existing conditions in Building 346.

Building 442—Stone Infantry Barracks

This single-story stone building, originally infantry barracks, currently serves as artifact and miscellaneous storage. Over the years, several wooden annexes have been added at the rear of the building (Figure 4). Plans include utilizing the front (east) of the building for interpretive displays and the back (west) for storage of artifact collections, most notably leather tack equipment. Additionally, one goal of the upcoming rehabilitation includes the removal of most of the wooden annexes. The original stone infantry barracks is U-shaped with each wing (north and south) of the "U" mirroring the configuration of the opposite wing.

Building 442 is currently equipped with a variety of climate control systems. A recent system serves a portion of the original barracks building. Twin condensers are located at the rear of the building, providing chilled water through original windows to air handlers located in the large original infantry sleeping quarters. A single overhead air-handling unit and outside chiller provide cool air to one of the wooden annexes in the northwest wing of the building. Window air conditioning units have been installed and are also operating in this portion of Building 442. The original northwest portions of the building are equipped with two separate antiquated air handlers that are served by an outside packaged condenser. This system was not operational at the time of the assessment. There are also portions of the building that are not equipped with any sort of air conditioning system (see Figure 4).

Heating is currently provided throughout the building by a series of individual hot water units. The hot-water for the heating system is provided by the boiler plant located in a building directly to the west of Building 442. The hot-water pipes are routed overhead to Building 442 and the two similar buildings to its north and south. The overhead pipes are a cumbersome and unsightly intrusion to the historic fabric of the building. Current plans call for the removal of the boiler plant and pipework.

Room 1, originally the southern barracks kitchen, is currently used for artifact storage. Plans call for its continued use as a collections storage area. The walls are finished with plasterboard and paint, the ceilings are historic beaded boards, and the floor keeps its historic wood finish. The room is not air conditioned; however, one heating unit services the room. A wooden restroom annex, now used as storage, is attached to this room.

Room 2 is currently used as storage for leather tack equipment. Plans call for its continued use as a collections storage area. No air conditioning vents service this room. However, two heating units are present.

Room 3, although currently used to store saddles, will be used for fixed exhibits. A large air handler, including a humidity control system, using exposed, overhead ductwork currently services this room. At the time of assessment the climate control system was set on 68° F and 45% relative humidity. However, a thermometer and hygrometer in the room read 72° F and 65% relative humidity. Three overhead units provide heat. A restroom annex is present on the west side of the room, and a working overhead loading door is present on the east side of the room.

Rooms 4 and 5 are small rooms in the center of the building. They will be used as public entries into the building and will house small museum displays. The thermostat in Room 4 recorded a temperature of 72° F at the time of assessment.

Room 6 is currently used for artifact storage. Plans call for its use as an interpretive, interactive display area. Similar to Room 3, this room has a large air-handler unit with humidity control and overhead ductwork. The humidistat appeared to be set at 57% relative humidity and the thermostat at 68°F. No independent thermometer or hygrometer was present in the room at

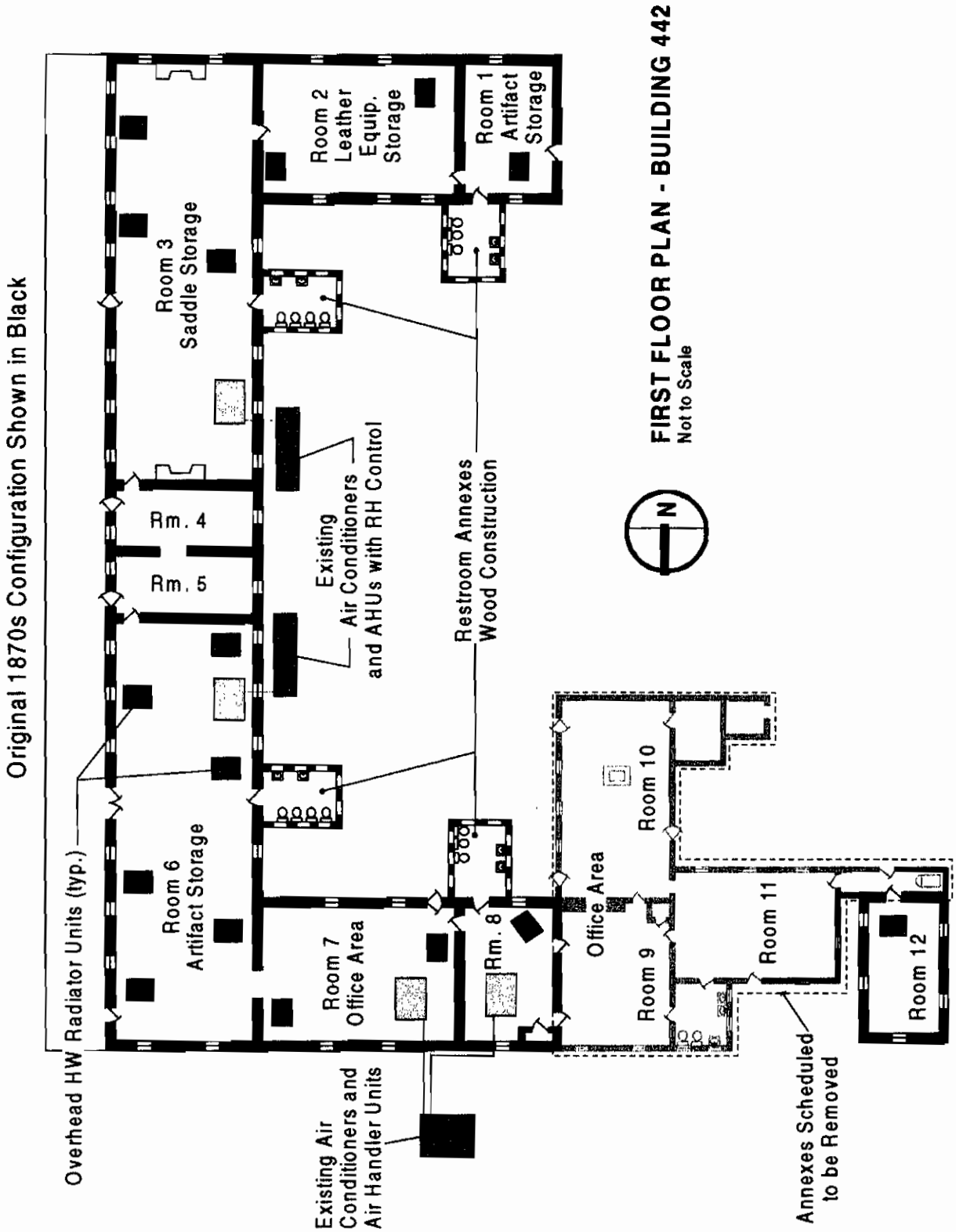

Figure 4. Existing conditions in Building 442.

the time of assessment to check the actual temperature and humidity. Also like Room 3, a restroom annex and overhead loading door are present.

Although now used for miscellaneous storage, Rooms 7 and 8 will also be used as interpretive display areas. Overhead air diffusers are present in both rooms, each serving an air-handler unit above the suspended ceiling system in Room 8. At the time of assessment the air conditioning was either shut off or not functioning. The thermostat in Room7 read 75°F. Two heating units were present. A leaking roof has caused considerable damage to the southeast corner of Room 7 and to the middle of Room 8.

Wooden annexes comprise Rooms 9, 10, and 11 which are scheduled for demolition during future renovations. However, if these rooms are not removed, they will be used for artifact storage. A window air conditioning unit provides cool air to these rooms. Overhead units also provide heat. A wall thermostat in Room 10 read 69°F at the time of assessment. A leaking roof has caused damage on the west wall of Room 11. A small restroom is present off the north side of Room 9, with accessibility through Room 11.

Room 12, originally the laundress house to the barracks, may be used as an extension to the interpretive display in the barracks. On overhead heating unit provides the only climate control in the room. The wall thermostat read 86° F at the time of assessment.

Taken together, the various climate control systems throughout the building provide inadequate and inefficient service to Building 442. Additionally, the humidity control systems present in the HVAC systems in Rooms 3, 6, and 7 do not appear to be working effectively, if at all.

3

Recommendations

Various types of heating, ventilation, and air conditioning systems and humidity control systems can be used to control the climate in museums. Although no system will be able to precisely control climate, especially in areas that are frequently accessed or where large numbers of people congregate, it can help to avoid large fluctuations that are damaging to collections. The design and implementation of any climate-control improvements or additions should be as simple as possible. A simple, updated system will ease the support and maintenance required by climate-control equipment while offering an acceptable degree of comfort and control. An elaborate climate-control system may prove to be unreliable and unmanageable, and may place collections, exhibits, and the historic buildings in greater danger than a simple, yet constant and effective system. Additionally, a simple system requires a lower initial cost and allows for greater flexibility as each building's use and condition evolve.

Other curation facilities have proposed the use of heat pumps for temperature and humidity control for historic buildings. Heat pumps offer ease in operation, the ability to be adapted to spaces without large ductwork, and reasonable energy efficiency. Heat pumps are small cabinet-sized machines that can be placed in a closet or other accessible enclosure. The units require relatively little maintenance and can be replaced as interchangeable parts if an individual heat pump fails. Identically sized heat pumps can be kept in stock by the museum or ordered without the delays associated with other more sophisticated equipment. Additionally, heat pumps can be configured to serve independent areas (zones), allowing for individual control, operation, and maintenance. Each unit can be controlled by a thermostat and served with piping from a central boiler and a central evaporative cooler. A zoned approach is useful when different areas require different climate control. This approach works well with the multiuse capacity of each of the three buildings under assessment. However, the heating capacity of heat pumps often requires supplemental heating systems for climates with extreme winters. Estimates have been provided for heat pumps in each building. With these advantages in mind, further design and calculations by a mechanical engineer could determine the ultimate feasibility of heat pump systems at Fort Sill.

In keeping with other general recommendations and zoning principles, humidification systems should be installed only where needed. Space programming should dictate which areas are most vulnerable to humidity fluctuations and which contents are most susceptible to relative humidity fluctuations. For large museum uses, such as those at Fort Sill, reheat dehumidification and steam humidification seem to work best (Haines 1987). Additionally, portable humidifiers and dehumidifiers are simple and effective ways of controlling conditions without a major investment. These can be used in conjunction with a larger system or in small rooms that require more humidity control. A danger, however, of using portable units lies in creating possible disadvantageous microclimates where relative humidity levels may fluctuate beyond the intended goal.

Several guidelines should be followed when installing humidification systems. It is desirable to connect the humidification control equipment directly to the building's plumbing system. This would eliminate the need for filling water tanks and controlling water from dehumidifiers. Any system will be ineffective if someone forgets to put water in the humidifier or if water removed from the air is spilled onto the floor. Also, a newly humidified or dehumidified space should be gradually introduced to the new systems. This will allow the building to adjust and will prevent damage to its historic features.

Improving the Efficiency of Climate-Control Systems

Simple architectural and general improvements would greatly enhance the effectiveness of any climate-control system at the Fort Sill Museum.

Create Vestibules and Air Locks

A simple solution includes installing a vestibule or air-lock entry at each building. This can be constructed inside the building to avoid adversely impacting the historic character of the outside. The problem of large volumes of outside air introduced at the building entry would be mitigated inside the vestibule, protecting the more sensitive areas of the building from wide fluctuations of temperature and humidity, while also easing the heating and cooling loads of the HVAC system. Using this same principle, outside air infiltration from cracks in walls and along windows and doors should also be reduced.

Create Space-Use Plan

An effective climate-control system can best be designed with a firm knowledge of the use of each space within the building. This is especially true with specialized use groups, such as museum exhibit areas and collections storage facilities. A thorough space and use program will greatly improve the design of new climate- control systems. With this information established, construction budgets and HVAC system designs can be tailored to each building and its new uses. A list of priorities should emerge as a guide to the wisest use of Fort Sill Museum's available space and climate-control funds. This list may include only basic climate control in unused areas and the installation of humidification equipment in only the most sensitive or vulnerable areas. In sum, the fragile nature of most of Fort Sill Museum's collections requires stabilized temperature and humidity levels. However, areas devoted to the storage of equipment or nonhygroscopic materials, like stone, may need less sophisticated measures.

Use Buffering Agents

Buffering agents can also be used as a supplemental means of improving climate around sensitive objects. This can include displaying or storing objects in containers, which minimize damage from handling, light, dust, pollutants, insects, water, and changes in relative humidity. Additionally, in the case of a loss of power, the air inside the containers changes at a much slower rate than the air in the building, providing increased protection for the object.

Monitor Climate and Collections

Monitoring of the effectiveness of the climate-control system can aid in improving its efficiency. A monitoring plan, which includes daily readings of temperature and humidity ranges, is imperative for the long-term success of any climate control system. Monitoring provides base-line environmental data, identifies problems that require special actions, indicates the effectiveness of previous corrective measures, provides information on daily, weekly, and seasonal trends, and determines the character of environmental zones within a structure.

Also, monitoring of the collections and building will ensure that the climate settings are not too cold or too hot for the artifacts being stored. An inherent danger with any historic building and climate-control system is that if the temperature is too high in a cold climate during the winter, condensation can occur in the interior of the stone walls and cause fracturing of the wall during freeze-thaw cycles. Monitoring of the temperature and humidity in the building can avoid this danger.

Provide Adequate Maintenance

Continued maintenance is also essential to the effectiveness of a climate-control system. New and improved climate-control systems for each of the assessed buildings is predicated on a single, imperative condition: in order to ensure the proper care of the museum's collections, a commitment needs to be made to the maintenance and care of the climate-control system. Without comprehensive, dedicated, and trained support to the facilities and climate-control equipment, any system will continue to provide ineffective service. Maintenance staff should have all of the necessary training in the use of the specialized equipment serving the museum collections.

Analysis and Cost Estimates Associated with Upgrading Climate-Control Systems

The following estimates do not include costs for the restoration or replacement of historic building features. The recommendations present options that disturb the historic fabric of each building as little as possible. Nevertheless, the estimates are of a preliminary and comparative nature. More detailed estimates are recommended subsequent to design activity.

Building 438 – Old Child Care Facility

Building 438 is currently divided into five separate climate-control zones (see Figure 2). The climate-control service to several zones is currently inadequate. The entry/reception area (Zone 1) suffers from temperature and humidity fluctuation. This is attributed to the introduction of outside air from the building's entrance. The southeastern archives room (Zone 4) suffers from rising temperatures. This is likely attributed to a combination of inadequate diffuser distribution and cooling capacity.

Current plans to construct a new wood fence around the air conditioning equipment should help to maintain the historic setting of the post. Considering the existing and planned uses of the building, the five existing zones remain the best solution for a division of climate systems.

A simple architectural solution to the fluctuations at the entry/reception area would be to construct a vestibule at the main building entry. This addition may solve the wide fluctuations in this area. A more immediate and direct temperature control system would also alleviate these fluctuations.

The current locations of the exterior chillers in the basement and main level mechanical rooms seem appropriate. Installing new ductwork in the basement/crawl space with diffusers within the main level floors seems feasible. If the building were to ever be rehabilitated to reveal the historic roof truss systems, this scheme would allow for the removal of the existing suspended acoustical ceiling tiles. Placing the ductwork in the basement could also eliminate the need for the main level mechanical room. If designed accordingly, the only climate-control intrusion into the main level historic fabric would be at the floor diffusers. The currently unused basement/crawl space would house all of the climate-control equipment and ductwork. This approach may be best applied with Scheme 3 (Figure 5).

Either way, the existing ductwork should be replaced. The limited number of diffusers in each room can result in microclimates that receive insufficient cooling, heating, and air circulation. The library area is especially susceptible to this effect. Also, accumulation at each diffuser suggests that the air handling units and ductwork are emitting particulates into the sensitive archives and library areas.

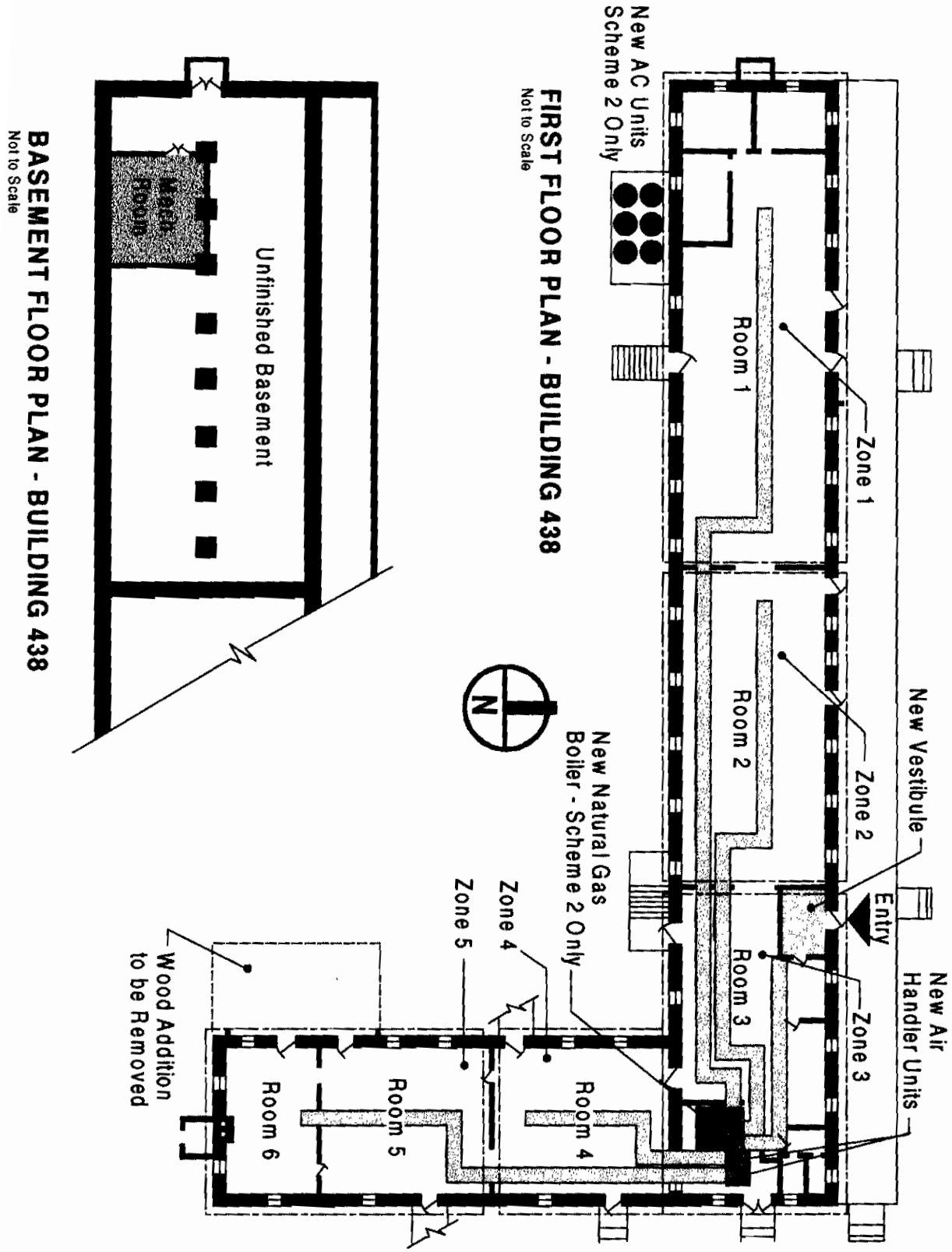

Figure 5. Schemes 1 and 2 for Building 438.

The following three schemes present reasonable solutions to the climate control problems of Building 438 (Tables 1, 2, and 3):

Scheme 1 includes a new air handling units, new overhead ductwork and diffusers, and new control systems. A new entry vestibule is included. The existing chiller and gas-fired furnace will remain. New chillers and furnace could be added to these new control systems, air handling units, and ductwork at a later date (see Figure 5).

Table 1. Building 438, Scheme 1 Itemized Cost Estimate

Item	Quantity	Unit	Unit Price	Cost
Demolition/Removal				
Remove existing HVAC equipment	1	EST	$ 1,000.00	$ 1,000.00
Remove existing ductwork	330	LF	$ 3.84	$ 1,267.20
Remove existing ceiling system	7,711	SF	$ 0.60	$ 4,626.60
Subtotal				$ 6,893.80
New Equipment				
Entry vestibule	54	SF	$ 13.60	$ 734.00
Air handler unit	5	EA	$ 1,800.00	$ 9,000.00
Ductwork	5,600	LBS	$ 6.40	$ 35,840.00
Diffusers	19	EA	$ 67.50	$ 1,282.50
Control systems	1	EA	$ 5,500.00	$ 5,500.00
Ceiling - Suspended Accoustical	7,711	SF	$ 2.15	$ 16,578.65
Insulation	Est. 10% of mechanical system costs			$ 5,162.25
Subtotal				$ 79,991.60
Contingencies			20%	$ 15,998.32
Total Estimated Cost				$ 95,989.92
	Cost per SF (7,711 gsf)			$ 12.45

Scheme 2 includes all of the new equipment noted in Scheme 1, with the addition of new packaged air conditioner units, natural gas furnace, and new humidification systems. The new air conditioners would be placed where the existing units are located (see Figure 5).

Table 2. Building 438, Scheme 2 Itemized Cost Estimate

Item	Quantity	Unit	Unit Price	Cost
Demolition/Removal				
Remove existing HVAC equipment	1	EST	$ 1,000.00	$ 1,000.00
Remove existing ductwork	330	LF	$ 3.84	$ 1,267.20
Remove existing ceiling system	7,711	SF	$ 0.60	$ 4,626.60
Subtotal				$ 6,893.80
New Equipment				
Entry vestibule	54	SF	$ 13.60	$ 734.00
Natural gas boiler	1	EA	$ 8,550.00	$ 8,550.00
Packaged air conditioner	1	EA	$ 5,825.00	$ 5,825.00
Air handler unit	5	EA	$ 1,800.00	$ 9,000.00
Ductwork	5,600	LBS	$ 6.40	$ 35,840.00
Diffusers	19	EA	$ 67.50	$ 1,282.50
Control systems	1	EA	$ 5,500.00	$ 5,500.00
Ceiling - Suspended Accoustical	7,711	SF	$ 2.15	$ 16,578.65
Humidifcation system	1	EA	$ 2,450.00	$ 2,450.00
Insulation	Est. 10% of mechanical system costs			$ 8,502.62
Subtotal				$ 101,156.97
Contingencies			20%	$ 20,231.39
Total Estimated Cost				$ 121,388.36
	Cost per SF (7,711 gsf)			$ 15.74

Scheme 3 includes the introduction of new heat pump units as the building's climate control system. Five units have been sized to replicate the five zones already in place within the current system. The heat pump units could be discretely place on the south and east elevations of Building 438 (Figure 6).

Table 3. Building 438, Scheme 3 Itemized Cost Estimate

Item	Quantity	Unit	Unit Price	Cost
Demolition/Removal				
Remove existing HVAC equipment	1	EST	$ 1,000.00	$ 1,000.00
Remove existing ductwork	330	LF	$ 3.84	$ 1,267.20
Remove existing ceiling system	7,711	SF	$ 0.60	$ 4,626.60
Subtotal				$ 6,893.80
New Equipment				
Entry vestibule	54	SF	$ 13.60	$ 734.00
Heat pump	5	EA	$ 4,650.00	$ 23,250.00
Ductwork	5,600	LBS	$ 6.40	$ 35,840.00
Diffusers	19	EA	$ 67.50	$ 1,282.50
Control systems	1	EA	$ 5,500.00	$ 5,500.00
Ceiling - Suspended Accoustical	7,711	SF	$ 2.15	$ 16,578.65
Humidifcation system	1	EA	$ 2,450.00	$ 2,450.00
Insulation	Est. 10% of mechanical system costs			$ 8,502.62
Subtotal				$ 104,249.56
Contingencies			20%	$ 20,849.91
Total Estimated Cost				$ 125,099.47
	Cost per SF (7,711 gsf)			$ 16.22

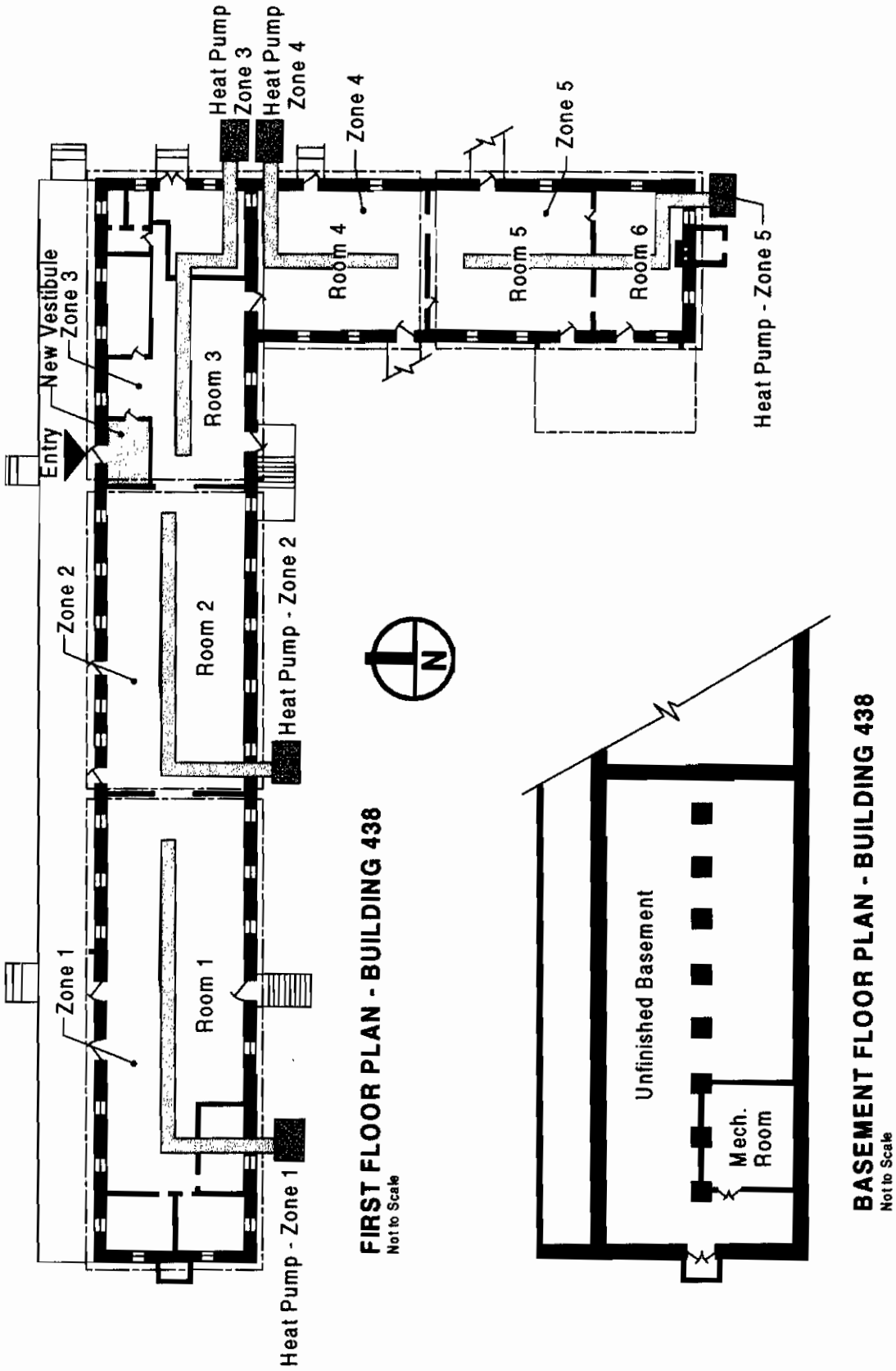

Figure 6. Scheme 3 for Building 438.

Building 346—Quartermaster Warehouse

The existing gas-fired heating units provide little worth salvaging for the installation of new climate-control systems in Building 346. If the Fort Sill Museum plans to use the building for artifact storage and exhibit, even for wagons and small artillery, it should install a comprehensive climate-control system. The existing units should be removed, and the design for new systems should proceed without the integration of these existing heating units.

Three zones seem to best divide the heating and cooling needs of Building 346 (Figure 7). The eastern, central, and western portions of the building present clear and sensible separation of uses and climate-control needs. Each zone could be serviced by its own condenser unit.

Enclosing the central portion of the building would create a vestibule/reception area that would help reduce any temperature fluctuations caused by the introduction of outside air at the building entry. This architectural solution would also create a more manageable climate-control zone in the eastern and western areas of the plan. The exposed historic timber frame roof would require a sensitive construction of the vestibule enclosure and application of insulation material.

The partial basement of Building 346 presents an appropriate space for a small mechanical room for the building's new air handlers and the necessary ductwork for the eastern and central portion of the building. Discretely placed floor diffusers would provide for supply and return air needs in the eastern and central zones. Because the western portion of the building has no usable basement, the ductwork could be feasibly routed through the floor in the central zone and provide unobtrusive overhead ductwork in the western zone.

The following two schemes present reasonable solutions to the climate-control problems of Building 346 (Tables 4 and 5):

Scheme 1 includes installing climate-control systems, including humidity controls, in the large eastern and western storage/exhibit rooms as well as the central portion of the building. It also includes the addition of partitions that would separate the central area from either end (see Figure 7).

Table 4. Building 346, Scheme 1 Itemized Cost Estimate

Item	Quantity	Unit	Unit Price	Cost
Demolition/Removal				
Remove existing heating units	7	EA	$ 100.00	$ 700.00
Mechanical Room				
Concrete slab	108	SF	$ 4.46	$ 481.68
Dry wall partitions	106	SF	$ 2.91	$ 465.60
Subtotal				$ 1,647.28
New Equipment				
Entry vestibule	118	EA	$ 13.60	$ 1,604.80
Natural gas boiler	1	EA	$ 8,550.00	$ 8,550.00
Packaged air conditioner	2	EA	$ 2,000.00	$ 4,000.00
Packaged air conditioner	1	EA	$ 1,275.00	$ 1,275.00
Air handler unit	1	EA	$ 3,175.00	$ 3,175.00
Ductwork	4,513	LBS	$ 6.60	$ 29,785.80
Diffusers	18	EA	$ 67.50	$ 1,215.00
Control systems	1	EA	$ 5,500.00	$ 5,500.00
New ceiling panels	320	SF	$ 3.00	$ 960.00
Humidifcation system	1	EA	$ 2,450.00	$ 2,450.00
Insulation	Est. 10% of mechanical system costs			$ 5,691.08
Subtotal				$ 65,853.96
Contingencies			20%	$ 13,170.79
Total Estimated Cost				$ 79,024.75
	Cost per SF (6,214 gsf)			$ 12.72

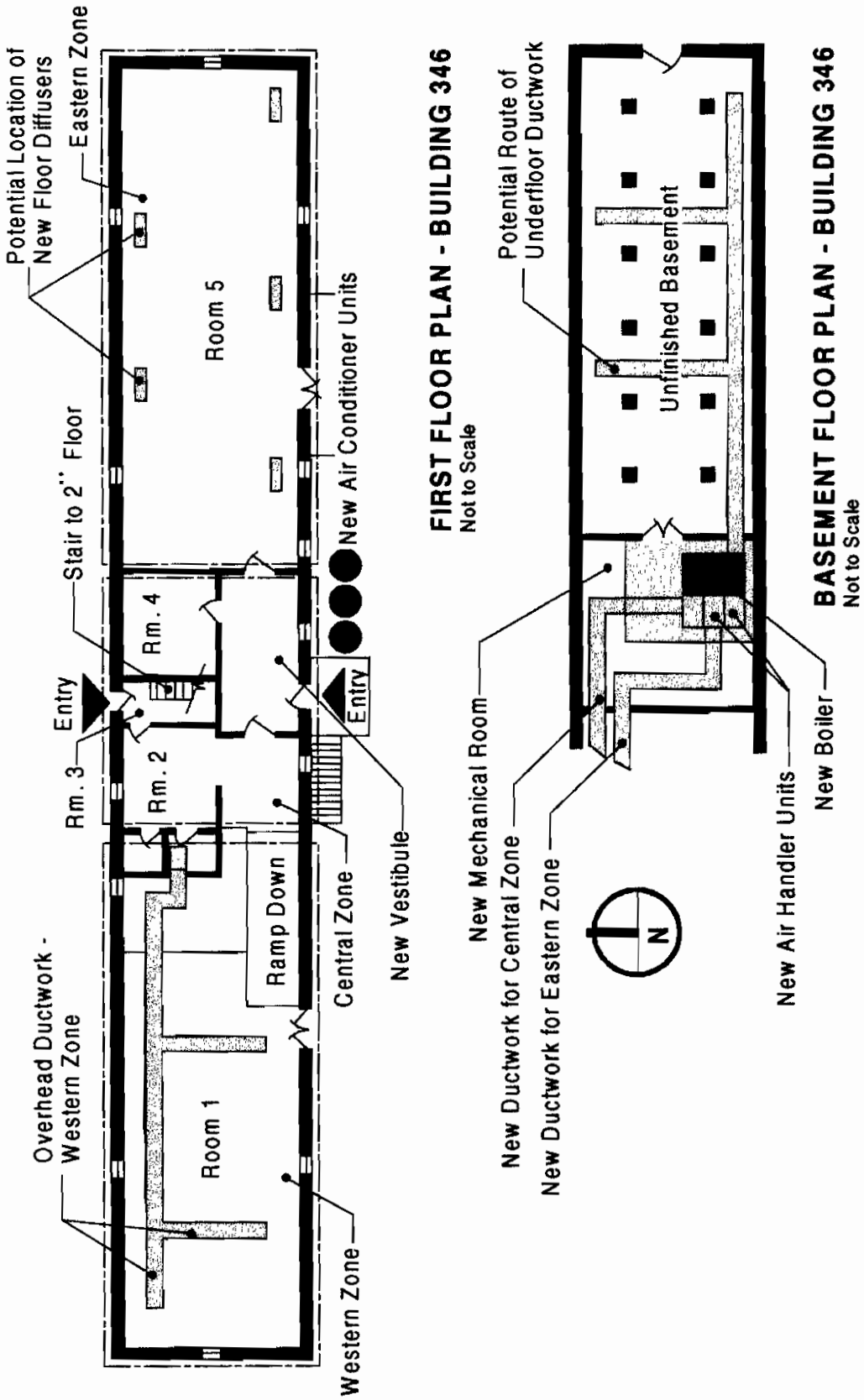

Figure 7. Scheme 1 for Building 346.

Scheme 2 includes the introduction of new heat pump units as the building's climate control system. Three units have been sized to accommodate the three zones already designated within the described system. The heat pump units could be discretely placed on the southern side Building 346 (Figure 8).

Table 5. Building 346, Scheme 2 Itemized Cost Estimate

Item	Quantity	Unit	Unit Price	Cost
Demolition/Removal				
Remove existing heating units	7	EA	$ 100.00	$ 700.00
Mechanical Room				
Concrete slab	108	SF	$ 4.46	$ 481.68
Dry wall partitions	106	SF	$ 2.91	$ 465.60
Subtotal				$ 1,647.28
New Equipment				
Entry vestibule	118	EA	$ 13.60	$ 1,604.80
Heat pump	1	EA	$ 9,667.50	$ 29,002.50
Ductwork	4,513	LBS	$ 6.40	$ 28,883.20
Diffusers	18	EA	$ 67.50	$ 1,215.00
Control systems	1	EA	$ 5,500.00	$ 5,500.00
New ceiling panels	320	SF	$ 3.00	$ 960.00
Humidifcation system	1	EA	$ 2,450.00	$ 2,450.00
Subtotal				$ 71,262.78
Contingencies			20%	$ 14,252.56
Total Estimated Cost				$ 85,515.34
	Cost per SF (6,214 gsf)			$ 13.76

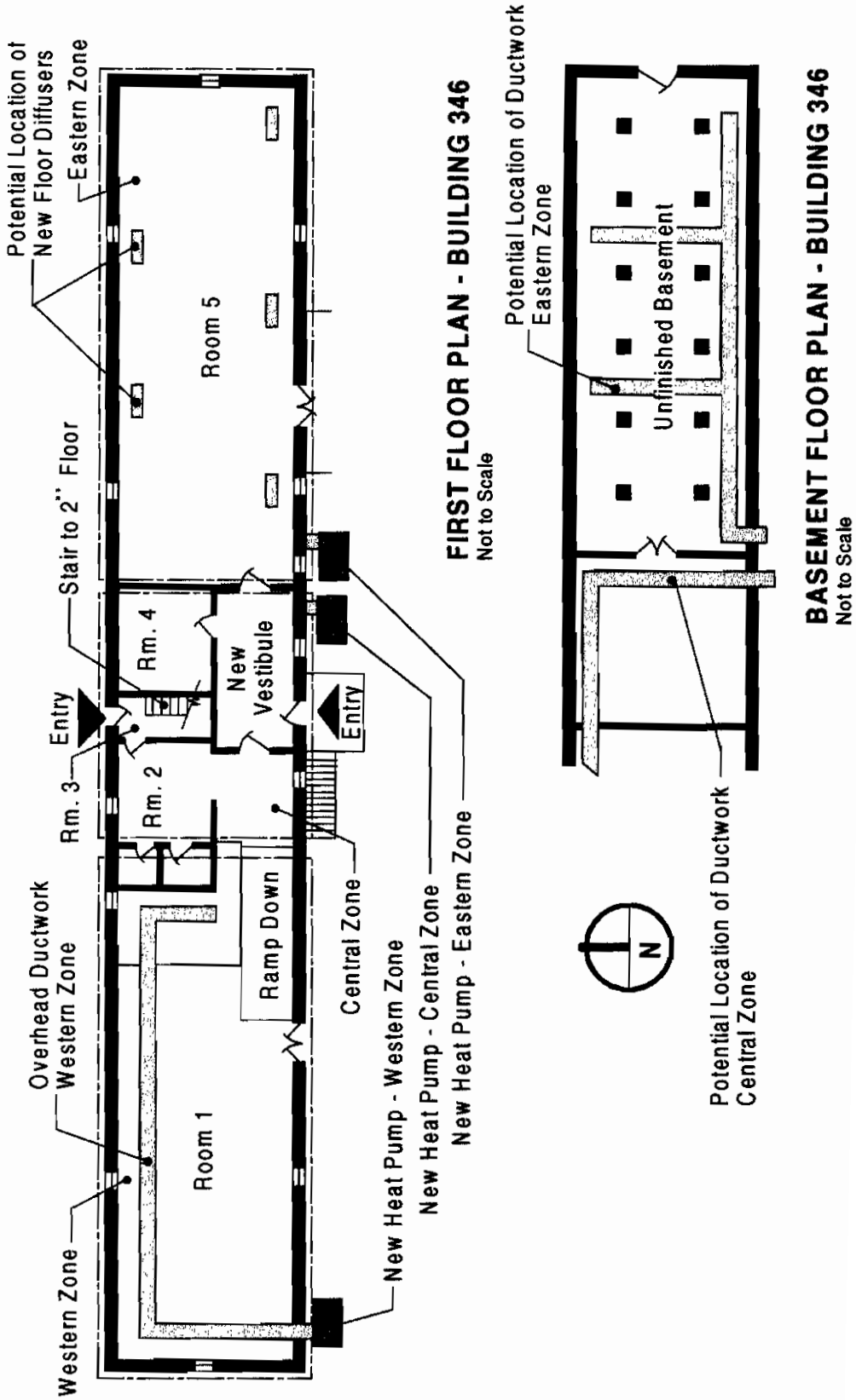

Figure 8. Scheme 2 for Building 346.

Building 442—Stone Infantry Barracks

The performance of climate-control systems could largely be improved by consolidating the variety of uses currently scattered throughout the building. Separating collections storage from public or daily use areas is a sensible strategy. Separating different types of artifact materials for storage would create even more manageable climate-control zones.

If Building 442 is to be returned to its original 1870s configuration, it seems best divided into four separate heating zones (Figure 9). New mechanical equipment should be housed within the two latrine additions currently attached to the north and south wings. The existing restroom facilities within these additions should be removed to accommodate new climate-control equipment. The two existing latrine additions attached to the east wing could be renovated as public restrooms, serving the renovated public areas of Building 442.

Ductwork should be routed overhead, either as exposed systems or above a new suspended ceiling system and the building's historic ceilings. New air conditioning condensers should be discreetly placed on the exterior of the building near the latrine additions/mechanical rooms. The combination of these strategies would seem to have the least impact on the historic fabric of Building 442.

The following three schemes present reasonable solutions to the climate control problems of Building 438 (Tables 6 and 7):

Scheme 1 includes the planned removal of the hot water heating source, the installation of new hot water boilers, cooling systems, and air-handler units, as well as humidity controls throughout the building. These systems would be divided into four heating and cooling zones (see Figure 9).

Table 6. Building 442, Scheme 1 Itemized Cost Estimate

Item	Quantity	Unit	Unit Price	Cost
Demolition/Removal				
Remove existing HVAC equipment	1	EST	$ 2,500.00	$ 2,500.00
Remove existing ductwork	250	LF	$ 3.84	$ 960.00
Remove existing ceiling system	1,530	SF	$ 0.60	$ 918.00
Subtotal				$ 4,378.00
New Equipment				
Natural gas boiler	2	EA	$ 5,125.00	$ 10,250.00
Packaged air conditioner	2	EA	$ 2,875.00	$ 5,750.00
Packaged air conditioner	2	EA	$ 1,275.00	$ 2,550.00
Air handler unit	4	EA	$ 2,225.00	$ 8,900.00
Ductwork	6,000	LBS	$ 6.40	$ 38,400.00
Diffusers	22	EA	$ 67.50	$ 1,485.00
Control systems	1	EA	$ 5,500.00	$ 5,500.00
Ceiling - Suspended Accoustical	1,530	SF	$ 2.15	$ 3,289.50
Humidifcation system	1	EA	$ 2,450.00	$ 2,450.00
Insulation	Est. 10% of mechanical system costs			$ 8,483.05
Subtotal				$ 91,435.55
Contingencies			20%	$ 18,287.11
Total Estimated Cost				$ 109,722.66
	Cost per SF (8,260 gsf)			$ 13.28

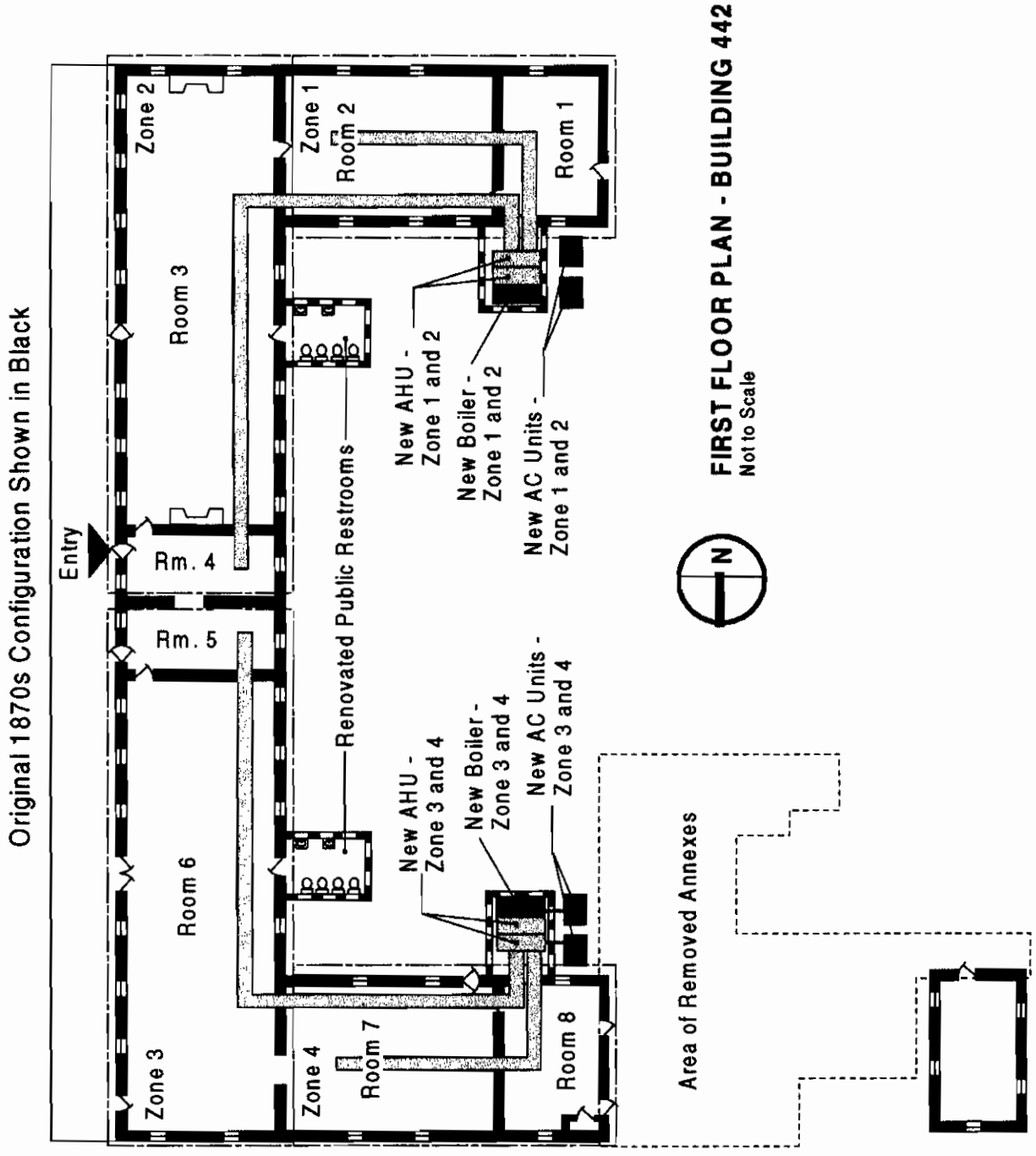

Figure 9. Scheme 1 for Building 442.

Scheme 2 also includes the planned removal of the hot water heating source and calls for the introduction of new heat pump units as the building's climate-control system. The previously described heat pump option seems best suited for consideration in Building 442. Four heat pump units have been sized to accommodate the four zones already designated within the described system. The heat pump units could be discretely placed on the north and western sides of Building 442 (Figure 10).

Table 7. Building 442, Scheme 2 Itemized Cost Estimate

Item	Quantity	Unit	Unit Price	Cost
Demolition/Removal				
Remove existing HVAC equipment	1	EST	$ 2,500.00	$ 2,500.00
Remove existing ductwork	250	LF	$ 3.84	$ 960.00
Remove existing ceiling system	1,530	SF	$ 0.60	$ 918.00
Subtotal				$ 4,378.00
New Equipment				
Heat pump	4	EA	$ 9,667.50	$ 38,670.00
Air handler unit	4	EA	$ 2,225.00	$ 8,900.00
Ductwork	6,000	LBS	$ 6.40	$ 38,400.00
Diffusers	22	EA	$ 67.50	$ 1,485.00
Control systems	1	EA	$ 5,500.00	$ 5,500.00
Ceiling - Suspended Accoustical	1,530	SF	$ 2.15	$ 3,289.50
Humidifcation system	1	EA	$ 2,450.00	$ 2,450.00
Insulation	Est. 10% of mechanical system costs			$ 10,495.05
Subtotal				$ 113,567.55
Contingencies			20%	$ 22,713.51
Total Estimated Cost				$ 136,281.06
	Cost per SF (8,260 gsf)			$ 16.50

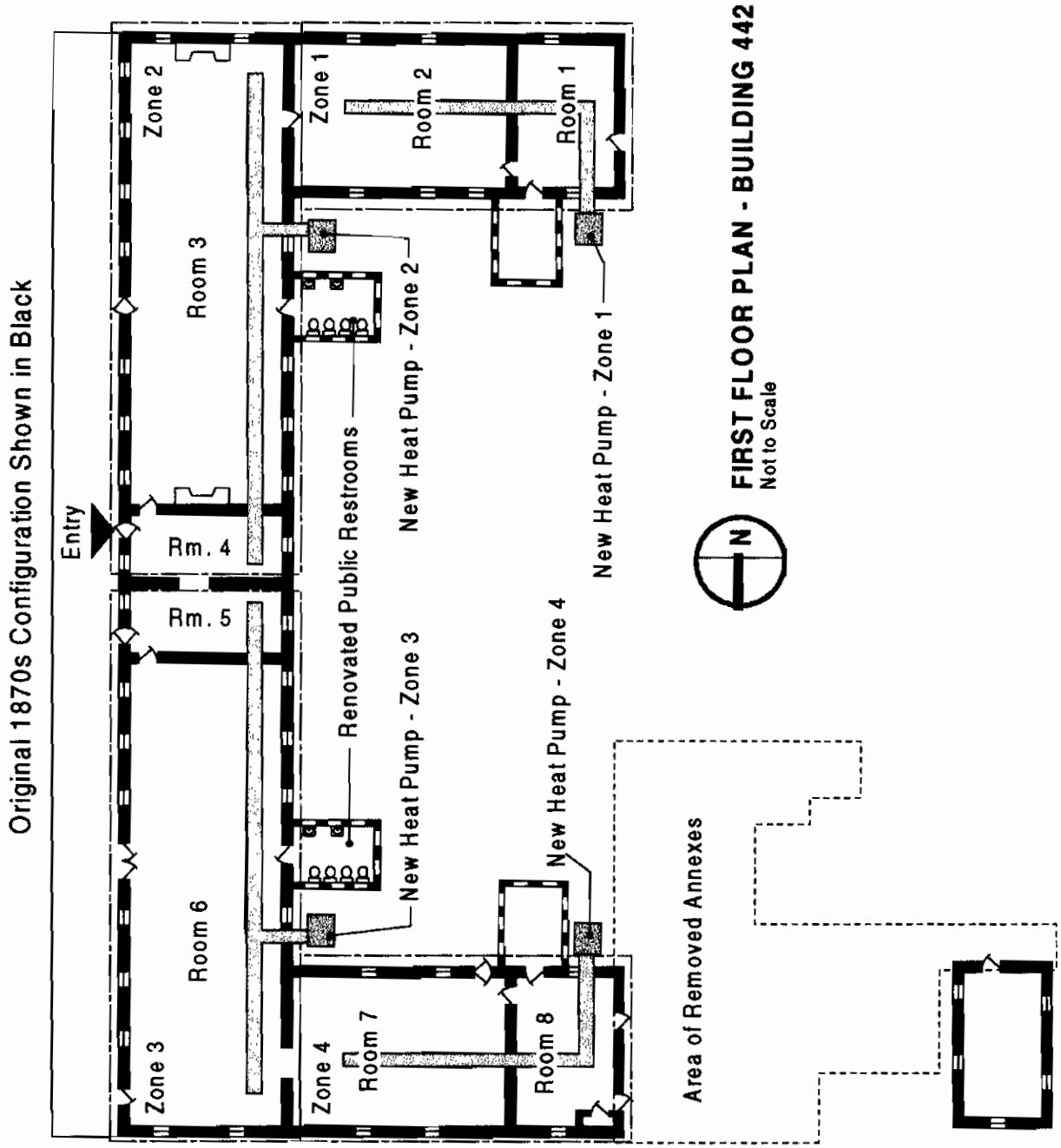

Figure 10. Scheme 2 for Building 442.

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Conclusions

Although no system is perfect, climate-control devices can help to avoid large fluctuations in temperature and relative humidity that wreak havoc with delicate museum collections, particularly organic (hygroscopic) materials. Improving the efficiency of installed climate-control systems by sealing buildings, creating microclimates, using buffers such as containerization, and monitoring can go a long way toward reaching the desired goal of climate stability. Fort Sill's varied collections require a comprehensive climate-control system in order to prevent further deterioration of this valuable historic legacy.

Recommendations offered in this report can assist Fort Sill with planning for the future of their historical collections. However, in order to reap the full benefits, consultation with architects, designers, engineers, building staff, maintenance staff, and administration will be beneficial. The final design of the climate-control system should take into account museum space allocation, potentials for microclimates, security, plumbing, accessibility, planned use patterns, and possibilities for additions or changes in the future.

Monitoring and adequate maintenance of the system are also crucial to its overall function. The specialized needs of the Fort Sill Museum collections require constant temperature and relative humidity levels. Fluctuations caused by electrical failure or energy conservation attempts will rapidly contribute to the degradation of these materials. Diligent care of the collections, including providing adequate temperature and relative humidity, will aid in preventing the loss of a valuable national heritage.

5

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