



*Predictive Method
for Weapon Storage Environments*

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Ronald L. Rabie

PREDICTIVE METHOD FOR WEAPON STORAGE ENVIRONMENTS

by

Ronald L. Rabie

Abstract

The Los Alamos National Laboratory Stockpile Monitor Program provides for the placement of Campbell Scientific Inc. data loggers in many weapons storage areas for the purpose of gathering environmental information such as relative humidity and temperature. Not all storage areas can be covered, however, so a means of estimating storage conditions is needed. This report describes one such technique.

The Initial Conditions

Numerous facilities worldwide are utilized for the storage of military hardware. In some instances these facilities have been instrumented for the purpose of determining the physical environment of the stored materials. Generally the facilities are of a standard reinforced concrete construction that is then covered with earth. Modifications to the standard single door, sealed construction style magazine include "drive through" capability (doors on both ends). Few if any of these structures employ active ventilation to control the environment inside the magazine. One of the goals of the Stockpile Monitor Program is to predict from outside temperature measurements, magazine type and location what the variation in temperature inside the magazine might be. This would be advantageous in that we simply can not measure environmental conditions at every facility of interest.

Variations In Outside Temperature

The inclination of the earth's axis of rotation to the plane of the ecliptic (the intersection of the plane of the earth's orbit about the sun with the celestial sphere) provides seasonal variations that become progressively more severe as latitude increases from the equator in both directions toward the poles. The earth's orbit about the sun is not exactly a circle but is close enough for most calculations of average weather variations. Assuming a circular orbit one may note that the variation of the angle of incident solar radiation to the axis of rotation of the earth ranges between 90 and about 67 degrees (where 90 - 23 gives 67 with 23 degrees being about the obliquity of the axis of the earth's rotation to the plane of the ecliptic). Thus one may approximately describe the variation of this angle as

$$\theta_i = 90^\circ - 23^\circ \sin(\omega t) \quad (1)$$

where the angles are explained above, and ω is the angular frequency of the earth's motion about the sun. The significance of this result is that one expects annual temperature

variations to behave similarly to the variation of the angle given above. One might be concerned that variations in latitude would be another complicating issue, but these simply shift the average annual temperature up or down as latitude moves nearer or further from the equator. Solar flux calculations, aimed at calculating temperature rises on oriented surfaces, however, do require corrections for latitude.

Magazine Behavior

Given an expected annual temperature cycle, one is confronted with the problem of predicting the temperature behavior of a given magazine. We assume that most magazines have little or no internal heat source of significance. In addition, we assume that most military magazines have little or no effective ventilation. Thus the predominant means of heat transport will be via conduction between the outside air and the inside of the magazine. In many cases the conduction path is tortuous, and there is a significant delay in the magazine's response to external temperature changes. Our data indicate that this delay is longest for those facilities that are conduction limited and shortest for those facilities having enhanced natural ventilation where convection may play a significant role. Regardless, there will be a lag of a few days to a few weeks between a change in the outside temperature and a corresponding temperature change in the magazine.

Measurements And Data

In order to build predictive models, detailed records of pit, magazine, and ambient temperatures are needed. We use Campbell Scientific data loggers in the Stockpile Monitor Program.¹ The Campbell Scientific CR10 is a rugged, well tested data logger/controller that can collect up to 12 single-ended channels of environmental information and store data in 64k of permanent memory. Simple algorithms to massage data, i.e., average, maximum/minimum values, etc., are easily programmed into the CR10. Data loggers are housed in sturdy, weather proof, fiberglass enclosures that can be located outside. As a hedge against data loss due to inadvertent power loss to the CR10, an auxiliary external storage module (SM192) with battery-backed RAM (random access memory) is attached to each data logger.

Temperature measurements supporting the modeling effort can be broken into three types, air, surface and soil. Air and soil temperatures may be obtained using YSI 010-44019A thermistors, while surface temperatures (i.e., wall or floor) are obtained with YSI 082-44019A surface mount thermistors. These thermistors function between -55°C and +85°C and are accurate to within $\pm 1.5^\circ\text{C}$ over the range employed. Typical data from Barksdale Air Force Base near Shreveport Louisiana are shown in Figure 1.

¹ The Los Alamos Stockpile Monitor Program (SMP) is a continuing effort designed to characterize the environmental conditions of weapon storage areas around the world. It has been described in a recent Los Alamos report (G. Buntain, Mike Fletcher, and Ronald Rabie, "The Stockpile Monitor Program," Los Alamos National Laboratory report LA-12796-MS [July 1994]).

**Outside vs. Inside Average Temperatures
(Barksdale, La.)**

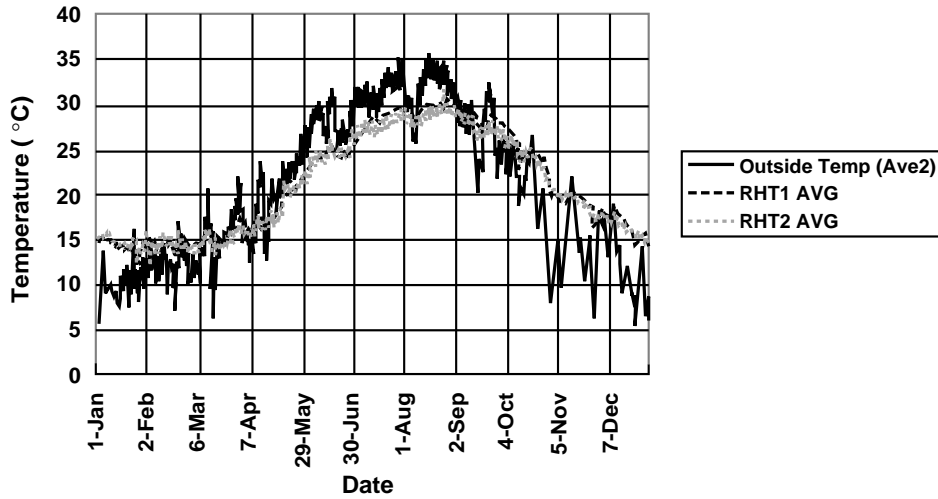


Figure 1. Shifted data for both outside and inside temperatures at Barksdale. In this plot the outside temperature data have been shifted to the left about 15 days so that the various maxima and minima coincide. The unshifted data are shown in Figure 2.

**Outside vs. Inside Average Temperatures
(Barksdale, La.)**

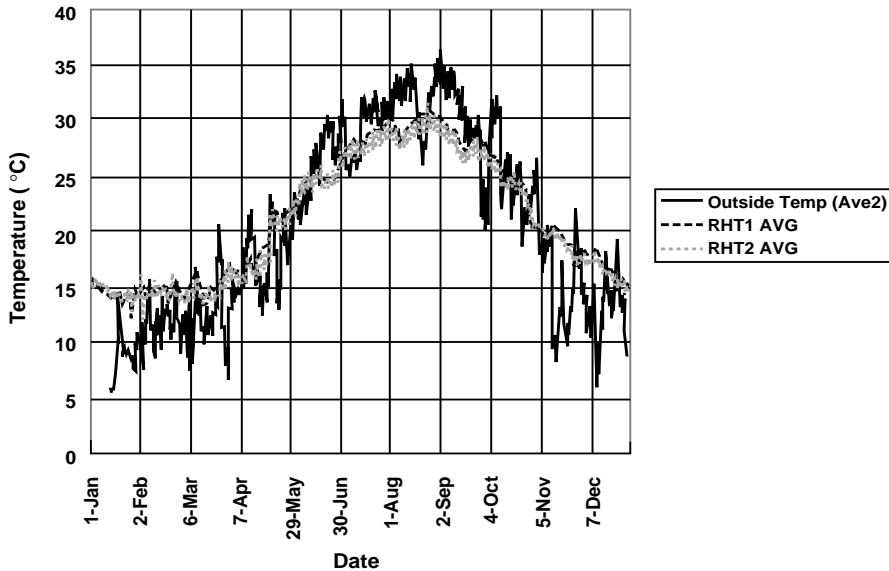


Figure 2. Unshifted data for Barksdale including outside and inside temperatures.

These data are essentially the raw data retrieved from the data loggers at Barksdale AFB. It is evident that these data have a “phase lag” brought about by the finite value of the thermal conductivity of the structure. As noted a shift in time of about 15 days fixes the data so that

the various features more nearly match. Another feature clearly seen in the data is that the magazine construction damps the extremes of both heat and cold in the outside environment. This thermal damping is about five to six degrees Celsius (9 degrees to 11 degrees Fahrenheit). It would appear that these observations could be applied to predict the thermal behavior of a wide variety of magazines given a reasonably smooth outside temperature measurement and a few data points inside the structures during the course of a year. While such a method might not be as rigorously defensible as our current instrumentation, it would have the advantage of being easily implemented.

The Model

Using the observation made above about the variation of the inclination of the earth’s axis of rotation we can describe the temperature behavior of the outside and inside of a given structure in a given location as

$$T_i = T_{\max_i} - \frac{\Delta T_i}{2} [1 - \sin(\frac{2\pi x}{365} - \delta_i)] \tag{2}$$

where the index ranges from 1 to 2 to cover inside and outside temperatures. The variable “x” is the Julian day counter (1 to 365) with 1 being January 1st. A simple examination of this system is shown in Figure 3 below which is a Mathematica calculation of these two equations plotted over one another to show the behavior.

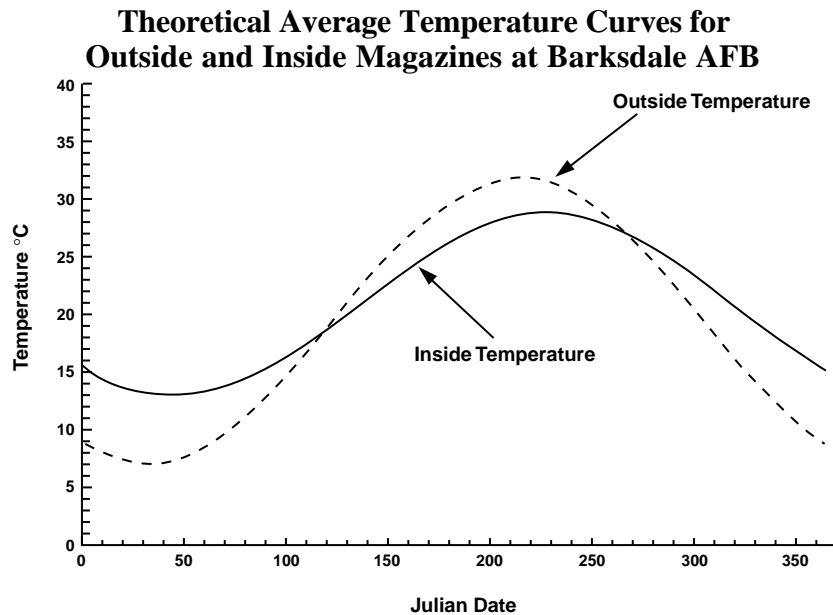


Figure 3. Mathematica calculation of Equations 1 and 2 plotted over one another.

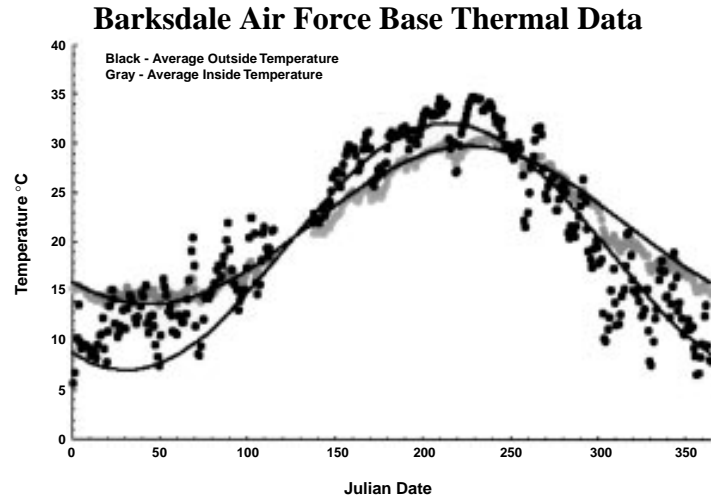


Figure 4. Average outside temperature (black), average inside temperature (gray), and theoretical temperature estimates plotted over the data.

Figure 4 combines the measured average daily outside temperature, the measured inside temperature and the two theoretical curves in Figure 3 for a particular storage structure in Barksdale to show the degree of agreement obtainable with simple functions. One must note that the weather peculiar to a given location will have variations season to season that can not be so readily explained. Examples that strongly affect local weather are mountain ranges, lakes, oceans etc. Nevertheless, we still anticipate an average sine-like (periodic) behavior over the course of a year.

Observation of the data in Figure 4 for the outside temperature suggests that the heating period is longer than the cooling period. We find this to be characteristic of outside temperature measurements made in North America. In addition, if the magazine interior is well connected to the outside environment (ample vents and chimneys), then we find that the interior temperature measurements track the shape of the outside temperature curves. In the case of the Barksdale data, it is evident that the magazines are relatively well isolated from the outside temperature.

Barksdale Air Force Base, Louisiana—Temperature Data

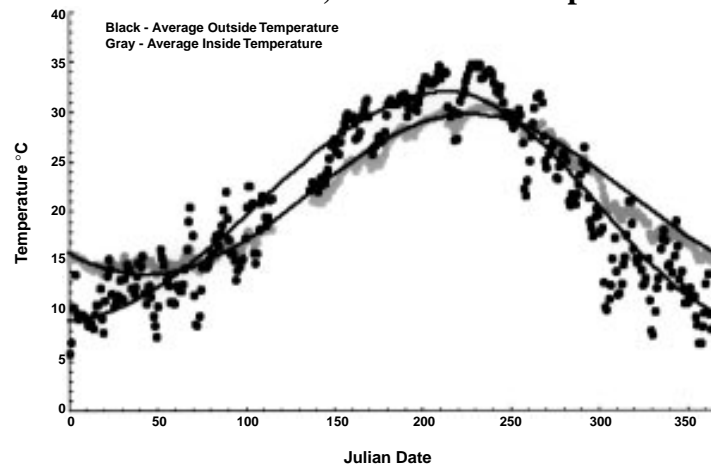


Figure 5. Data from Barksdale AFB with a two-period sine function fit to the outside temperature data. Black represents average outside temperature data; gray represents average inside temperature data.

Figure 5 shows an improvement to the outside temperature data taken from Barksdale AFB. Observations of the outside temperature data indicate a temperature cycle that has at least two periods, a heating period of about 14 months and a cooling period of about 10 months. The obvious condition is that the sum of these two periods divided by two must be twelve. The fit to the outside temperature data shown in Fig. 5 is such a two-period function. One notices a significant improvement from the single-period fit shown in Fig. 4 above.

Finally, we have wondered about the feasibility of using local meteorological data rather than that of our own installations to estimate the thermal response of the magazines. Shown in Figure 6 is a comparison of the US weather service data for Shreveport Louisiana (black) to that of the data accumulated for Barksdale (gray) by Los Alamos data loggers. The comparison is sufficiently favorable to allow direct use in the analysis suggested above. Thus it appears possible, given a magazine's characteristic thermal response, to predict with reasonable accuracy the temperatures internal to the magazine with no or minimal data from inside the magazine. The procedure for carrying out such a plan would be to smooth the outside temperature data, fit the data to a functional form (such as the one used above), apply the thermal delay times and temperature offsets for the given magazine type to the fit, and read off the estimated magazine temperature.

Comparison of Weather Bureau Data for Shreveport to Barksdale Data from Los Alamos Measurements

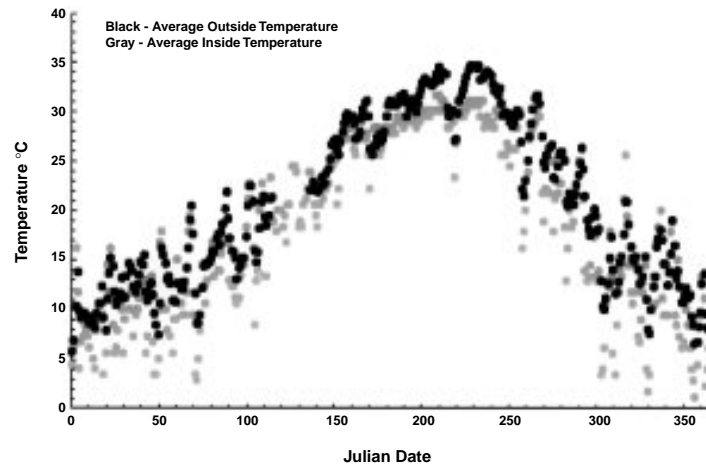


Figure 6. A comparison of US weather service data for Shreveport Louisiana (black) to that of the data accumulated for Barksdale (gray) by Los Alamos data loggers.

Conclusion

The simple analysis conducted above suggests that we can get reasonable magazine temperatures in locations where we have only external weather data and minimal magazine information. **While these temperature estimates will necessarily be average values,** they will allow us to extend our environmental studies to virtually any location without the need for extensive and expensive instrumentation. Data used in this analysis resulted from the work of Greg Buntain, Mike Fletcher, Gene Mortenson and Gene Taylor at Los Alamos National Laboratory.

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