Understanding Preservation Metrics

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This document is an attempt to clarify the extremely complex concepts behind IPI's environmental monitoring metrics, the origins of the values used, the methods of calculation, and other technical issues.

While conservators and facilities managers in museums, libraries, and archives would prefer simple, one-size-fits-all guidelines for storage environments, the interactions of environment and collections are too complex to be accommodated by a single, simple recommendation, such as 70°F, 50% RH. Such recommendations fail to acknowledge that the effects of the environment follow a continuum. There is no clean line of temperature or RH that can be said to divide storage conditions into bad and good. In addition, few institutions manage to meet conventional storage recommendations, such as the common 70°F, 50% RH. Furthermore, this recommendation doesn't say anything about the consequences of not meeting this requirement. IPI's environmental metrics attempt both to account for the complexities in the relationships between deterioration and temperature, humidity, and exposure time, and to provide an approximation of the quality of the environment (whether good or bad) based on specific deterioration pathways.

In order to apply any kind of general index value to a specific collection, it is critical to know the nature of the objects in the collection and any life-determining sensitivities they may have. The primary weakness of a collection of iron pots, for example, is iron oxidation, not mold growth. Similarly, hydrolytic deterioration is not the greatest threat to wooden furniture; dimensional change causing weakening of joints is the more likely issue of concern.

Collection materials stored without protective enclosures don't respond immediately to changes in temperature or relative humidity. The resulting time delay in response and reduction of environmental impact is accounted for by using a running average of the measured temperatures and RH levels. Equilibrium studies on a variety of objects were the basis for the use of a running average.

Time-Weighted Preservation Index (TWPI)

Preservation index (PI) and time-weighted preservation index (TWPI) are based on the science of chemical kinetics, which deals with the rates of chemical reactions. For some time, preservation scientists have used the laws of chemical kinetics in formulating environmental analysis tools. The isoperm concept, invented by Donald Sebera, formerly of the Library of Congress, used accelerated-aging data and kinetics principles to apply relative "permanence-factor" rankings to different combinations of temperature and humidity. TWPI does likewise, but it goes further by allowing for life expectancy values expressed in years instead of relative factors. The main advantage of TWPI is its ability to condense a whole period of changing temperature and RH conditions into one value by properly averaging or "weighting" how much each interval of time contributes to the decay rate overall.

The preservation index, or PI, of a storage environment expresses the "preservation quality" of that environment, at the time of measurement, for organic materials (carbon-containing materials like plant and animal products, plastics, paper, dyes, etc.). PI values, expressed in units of years, show us the combined effect of temperature and RH on the decay rate of vulnerable organic materials in collections and give us a general idea of how long it would take for them to exhibit significant deterioration, assuming that the temperature and RH did not change from the time of measurement onward. (Significant deterioration here means noticeable discoloration or embrittlement or other changes that involve a serious loss of appearance or functionality.) However, nearly every storage environment does change—with the weather, with the seasons, or by conscious actions to save money or to be more comfortable. The TWPI is a kind of "average PI" for situations where temperature and RH vary over time.

The PI concept uses as a benchmark the approximate lifetime at room temperature of a typical "preservation problem object" such as acidic wood-pulp paper, color photos and movies, nitrate and acetate film, herbarium specimens, and magnetic tape. All of these deteriorate significantly in about 50 years at room temperature and moderate RH. PI values in years were designed so that the PI of 68°F (20°C), 45% RH is 50 years, to reflect the behavior of such problem objects. If a storage condition has a PI of 100 years, it means that a problem object like acidic paper would require 100 years to discolor to the same extent that it would in 50 years at room temperature and moderate RH. PI values can still be used in a purely relative sense. If a storage condition has a PI of 200 years, then organic materials would last four times longer in that particular condition than they would at room temperature where the PI is only 50 years. PI values have meaning in a relative sense for all organic objects, and have meaning in a literal sense as life expectancy values for short-lived preservation problem objects. PI can be helpful in planning new storage areas, but its main practical use is for calculating TWPI.

If PI values are obtained at regular time intervals, a relatively simple recursive calculation (one that is repeated again and again with new data) can produce a single number that accurately expresses the average rate of deterioration for the time period. This number is the TWPI. Because it is an averaged value, the only point of interest is the final result.

Metric: TWPI

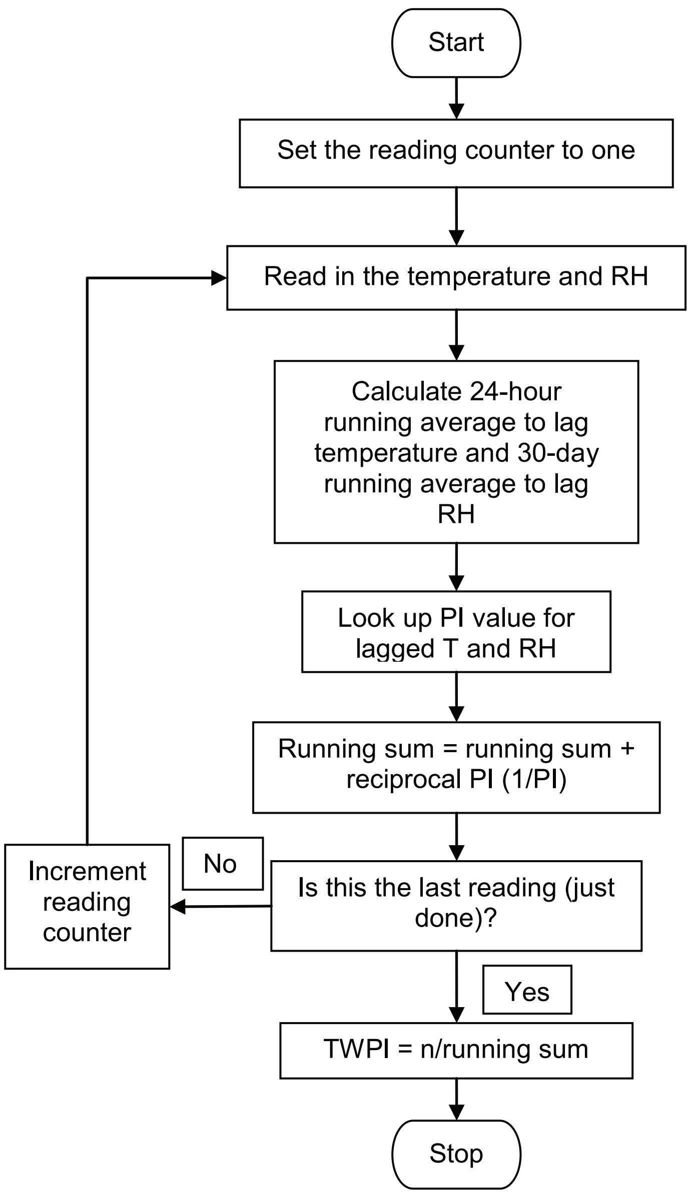
Applies to: All organic materials (paper, textiles, plastics, dyes, leather, fur, etc.)

TWPI Value	Interpretation
1-45	Poor environment; fast change
45-75	OK environment
75-100	Good environment
>100	Excellent environment

Measures: Effect of environment on spontaneous chemical change or natural aging

Interpretation: Higher is better

Calculation: (See flow chart.) In the implementation of TWPI, temperature and RH pairs are read. Temperature is lagged by using a 24-hour running average. RH is lagged by using a 30-day running average. The lagged values are checked in a look-up table that provides the PI value at that condition. The PI values for all of the temperature/RH readings are then properly averaged to produce the TWPI value.



Mold Risk Factor (MRF)

One of the more common biological problems in collections is mold growth. Traditional storage recommendations for preventing mold growth are based on a vague relative humidity point separating safe storage from unsafe storage. The most common species found on collection materials belong to the genus Aspergillus. Another group of xerophilic molds belong to the genus Penicillium. The mold-growth analog to PI was produced starting from a growth model equation created by a microbiologist, who tested the general model by tracking dry weight gain and aflatoxin production in various mold colonies and in different temperature and humidity conditions. The philosophy of the model is that there is an optimum temperature for growth and that as the environment gets hotter or colder the growth rate slows down. There is also an optimum temperature for which the least amount of water is required for growth; as the temperature gets higher or lower, the minimum relative humidity required for growth increases. The boundaries and the shape of the growth model are governed by a number of constants. These constants were determined by observations from conservators, microbiological growth studies on dried beans, grains, and grasses, and relative growth studies on agar plates. In recognition of the fact that storage environments often don't have constant temperature and humidity conditions, the mold risk factor (MRF) includes integration of the approximate growth progress during each reading period.

Metric: MRF

Applies to: All organic materials or inorganic materials with organic films

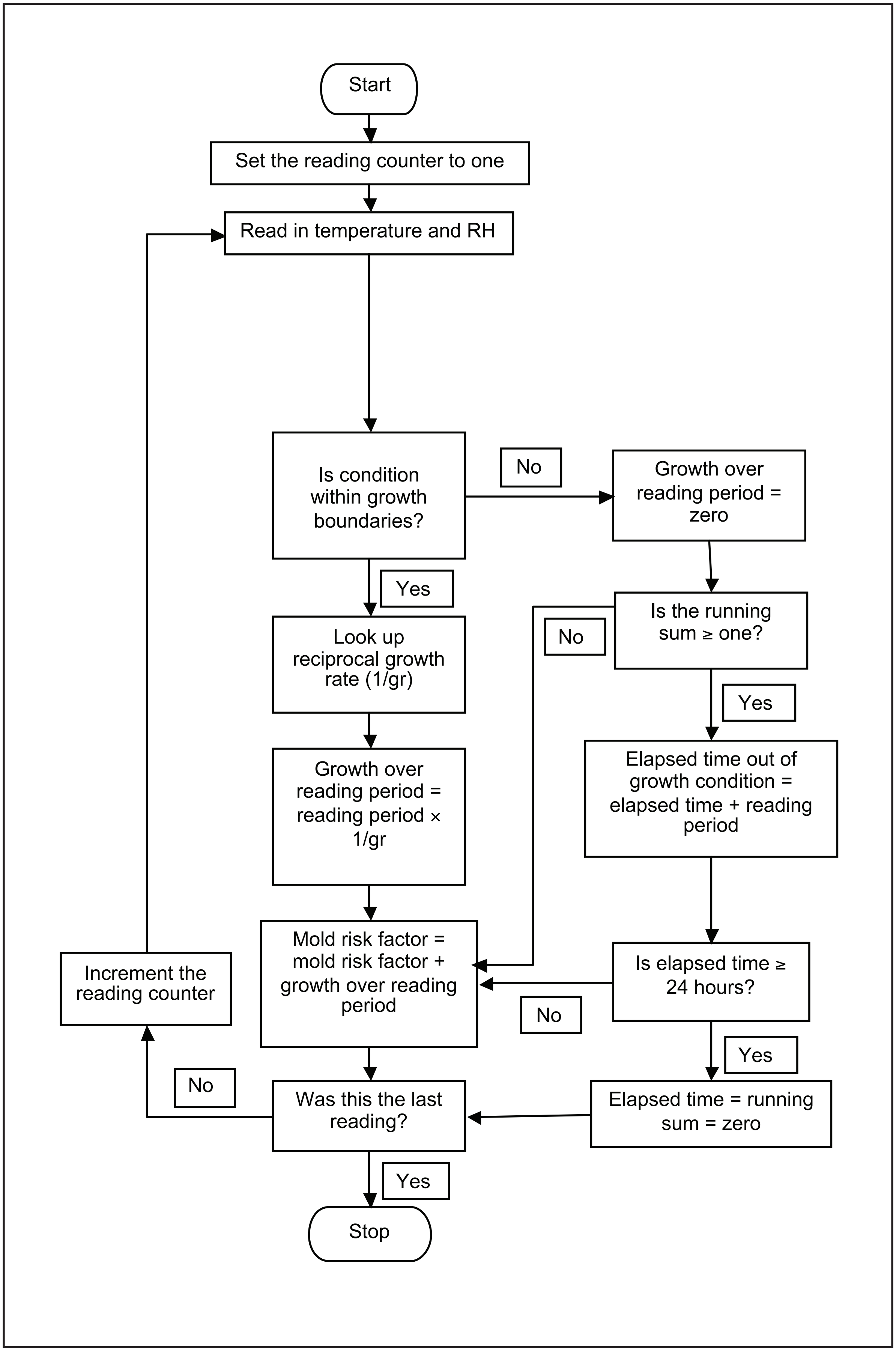
MRF	Interpretation
0	Ideal
0-0.5	Good
0.5-1.0	Some risk
1.0	Potential for active mold
>1	Active mold

Measures: Risk for growth on objects of xerophilic mold species

Interpretation: Lower is better

MRF may rise and fall over the course of the year or more of recorded data; therefore, the local maximum values are of interest, and not necessarily the final value.

Calculation: (See flow chart on page 5.)
Temperature and RH conditions are checked in a look-up table. Growth rates in the table are expressed in days to germination. If conditions are favorable for growth, then the growth rate is read from the table and the reciprocal growth rate is calculated. Reciprocal growth rates are expressed as fractions of the way to germination per day. This value is multiplied by the reading period expressed in days. The result is the fraction of the way to germination that has occurred during the reading period. These fractions are added as a running sum. If conditions are not favorable for growth, then nothing is added to the running sum. According to one microbiologist, a number of xerophilic species have conidia (spores) that can survive unfavorable conditions. Apparently, during unfavorable periods, these conidia simply go dormant and pick up again when conditions become favorable. Therefore, the running sum is maintained through unfavorable conditions even though no progress in growth is added. Once the running sum has reached one, there is a good chance (under ideal conditions of darkness, with still air) that some xerophilic species of mold have germinated and are now in the vegetative state. Once germination has occurred, it is assumed that the mold won't survive more than 24 hours if conditions are dry, in which case the running sum is reset to zero (start with new conidia) and the running sum starts again.


Start
Set the reading counter to one
Read in temperature and RH
Is condition within growth boundaries?
No
Growth over reading period = zero
Yes
Look up reciprocal growth rate (1/gr)
Is the running sum ≥ one?
No
Yes
Growth over reading period = reading period × 1/gr
Elapsed time out of growth condition = elapsed time + reading period
Mold risk factor = mold risk factor + growth over reading period
Increment the reading counter
Is elapsed time ≥ 24 hours?
No
Yes
No
Was this the last reading?
Elapsed time = running sum = zero
Yes
Stop

Maximum Equilibrium Moisture Content (MaxEMC)

This metric evaluates the risk of metal corrosion in a storage environment. A model for this metric would be extremely complex to create, since temperature and RH will affect not only the rate of reaction, but also whether or not the reaction will occur at all. Therefore, maximum equilibrium moisture content (MaxEMC) is used as an approximation to include time and, primarily, RH. While RH could be used directly with a running sum over time, MaxEMC is convenient, since it has to be calculated for the mechanical damage metrics (see Minimum and Maximum Equilibrium Moisture Content, below). The United States Forest Products Laboratory (USFPL) has equations that combine temperature and RH to produce a %EMC for an average species of wood. The temperature and relative humidity values used in the calculation are lagged in the usual way using a 24-hour running average for temperature and a 30-day running average for humidity.

Metric: MaxEMC

Applies to: Metals

Measures: Effect of the environment on metal corrosion

Interpretation: Lower is better

MaxEMC	Interpretation
<7%	Good
Between 7% and 10.5%	OK
Greater than 10.5%	Risk

Calculation: See Minimum and Maximum Equilibrium Moisture Content, below.

Minimum and Maximum Equilibrium Moisture Content (MinEMC and MaxEMC)

This metric deals strictly with physical deterioration and not with potential for mold growth or rate of chemical decay. High or low EMC may cause damage to certain types of organic materials, for example, the opening of cracks in panel paintings on wood and the failure of wood joints in furniture. The USFPL provides equations that combine temperature and RH to produce %EMC values for an "average" piece of wood. Temperature plays a lesser role than RH. Temperature and RH values are lagged by using a 24-hour running average for temperature and a 30-day running average for relative humidity. These lagged values are plugged into the USFPL equations to produce a %EMC value. These EMC values are sorted to find the highest and lowest in magnitude, and each value is evaluated separately.

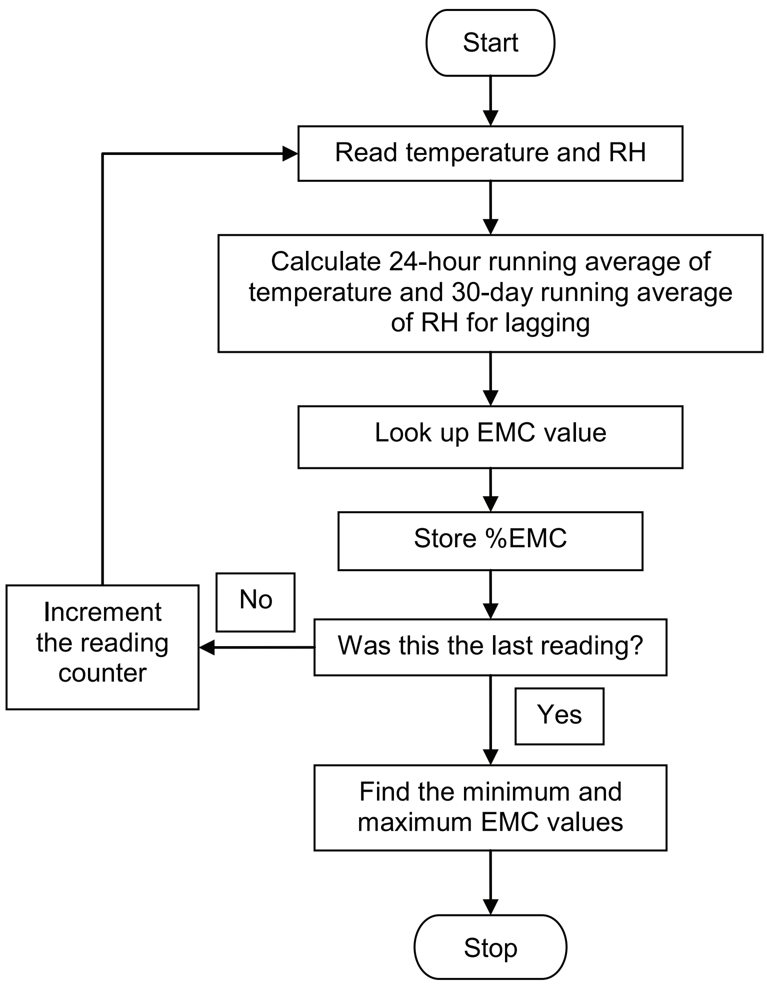
Metric: MinEMC and MaxEMC

Measures: Potential for physical damage in organic materials caused by too much adsorbed water or too little adsorbed water.

Interpretation: This index is combined with maximum percent dimensional change (%DC) as a gauge of potential for physical or mechanical damage.

Condition	Interpretation
MinEMC greater than 5% and MaxEMC less than 12.5%	Good
MinEMC less than 5% or MaxEMC greater than 12.5%	Risk

Calculation: (See flow chart.) Read in temperature and RH. Lag conditions by calculating 24-hour running average for temperature and 30-day running average for humidity. Look up %EMC. Sort to find minimum and maximum values.



Maximum Percent Dimensional Change (Max %DC)

There is concern about physical damage caused by changes in dimension. The USFPL has published equations that use temperature and RH to determine %EMC and additional equations that use %EMC to determine dimensional change from a 10% EMC level. These relative dimension values can be used to calculate a metric based on the magnitude of the change from the minimum to the maximum dimension. Rate of change is not taken into account yet.

Metric: %DC

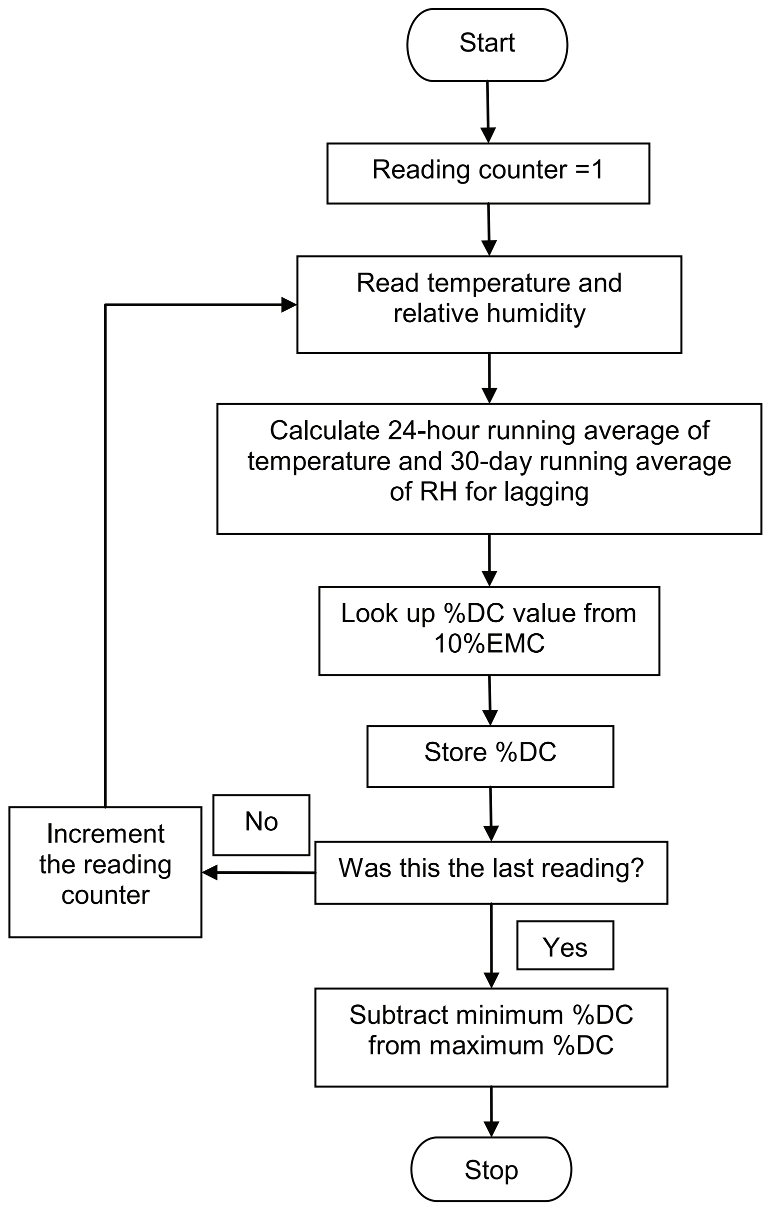
Applies to: All organic materials

Measures: Effect of the environment on (primarily) EMC-driven dimensional change. For organic materials, water content has a much greater effect on dimensional change than temperature. For example, the humidity coefficient of linear expansion for average wood is roughly 0.05% per %RH. The thermal coefficient is 0.0006% per Celsius degree. In approximate terms, a 100-Celsius-degree change would be required to make an average piece of wood change dimensionally the same amount as a 1% change in RH. The larger thermal effect is a result of thermodynamic law that says that the EMC of adsorbant materials, such as wood, paper, plastics, and gelatin, decreases at constant RH as temperature increases. An average piece of tangentially cut wood measured parallel to the fibers is used as an index of dimensional change induced by a changing environment.

Interpretation: Lower is better. Maximum percent dimensional change is combined with minimum and maximum %EMC to provide an index for potential physical damage in organic objects caused by the objects being too dry, too wet, or changing size too much.

Conditions	Rating
%DC less than 0.5%	Good
%DC less than 1.5%	OK
%DC greater than 1.5%	Risk

Calculation: (See flow chart on page 9.) Temperature and RH values are lagged using a 24-hour running average for temperature and a 30-day running average for RH. These lagged values are used to look up dimensional change values from 10% EMC for an average piece of tangentially cut wood measured parallel to the fibers. It is not known what the starting dimension was prior to the environmental monitoring, but it is assumed that the average dimension of the wood should not change from year to year. However, a linear renormalization to set any other %EMC as the “zero” point wouldn’t change the magnitude of the difference between the maximum and minimum values. Therefore, the minimum value can simply be subtracted from the maximum value to find the maximum dimensional change.


Start
Reading counter =1
Read temperature and relative humidity
Calculate 24-hour running average of temperature and 30-day running average of RH for lagging
Look up %DC value from 10%EMC
Store %DC
Was this the last reading?
No
Increment the reading counter
Yes
Subtract minimum %DC from maximum %DC
Stop