NRC Publications Archive Archives des publications du CNRC

Weather and the deterioration of building materials

Boyd, D. W.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version
acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

ASTM Special Technical Publication, 691, pp. 145-156, 1980

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=9e581d9f-856e-44f2-afb2-1977014af54a>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=9e581d9f-856e-44f2-afb2-1977014af54a>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research
Council Canada

Conseil national de
recherches Canada

Canada

8236

National Research Council of Canada
Conseil national de recherches du Canada

Ser
THL
N21d

no.933
cop. 2

BLDG.

WEATHER AND THE DETERIORATION OF BUILDING MATERIALS

by D.W. Boyd

ANALYZED

Reprinted from
Durability of Building Materials and Components
American Society for Testing and Materials
Special Technical Publication 691, 1980
p. 145 - 156

BBR Paper No. 933
Division of Building Research

Price \$1.25

OTTAWA

09058

NRCC 18635

CISTI/ICIST

3 1809 00210 0250

SOMMAIRE

Des tentatives faites par le passé pour prédire les effets de la température sur la détérioration des matériaux de construction ne furent souvent guère plus que des spéculations. L'inefficacité des résultats est abordée en prenant des cycles gel-dégel et des précipitations de pluie annuelles comme exemples. Des rapports empiriques plus précis devront se fonder sur des essais réalisés sur place ou en laboratoire et peuvent exiger des analyses de température particulières telles que l'étude sur la corrosion des métaux, l'analyse de la température pour eux ou plusieurs éléments. Le climat météorologique qui sont généralement ceux qu'il peut se procurer.

Weather and the Deterioration of Building Materials

REFERENCE: Boyd, D. W., "Weather and the Deterioration of Building Materials," *Durability of Building Materials and Components*, ASTM STP 691, P. J. Sereda and G. G. Litvan, Eds., American Society for Testing and Materials, 1980, pp. 145-156.

ABSTRACT: Early attempts to predict the effects of the weather on the deterioration of building materials were often little more than speculation. The inadequacy of the results is discussed using freeze-thaw cycles and the annual driving rain index as examples. More precise empirical relationships will have to be based on laboratory or test-site observations and may require special weather analyses such as the humidity tables prepared for a study of corrosion of metals. More complex relationships are being found and the analysis of the weather often will involve the study of the coincident values of two or more elements. The research scientist should be aware of the weather data now generally available and the types of analyses that could be provided.

KEY WORDS: weathering, corrosion, environments, deterioration, durability, climatology, exposure, building materials

The main purpose of this conference is to discuss the durability of building materials with the ultimate objective of finding a way to predict the rate of deterioration of any material in any location. The obvious and straightforward method is to expose all materials at many locations for many years and observe the results. This very reliable method has eliminated many unsatisfactory materials, and has shown the limitations of some materials and the great durability of others. Some stones have stood for thousands of years. Wood, concrete, bricks and mortar may survive for a few hundred years, but have been known to rot or crumble in a few decades. Why should this be? Apart from differences in the properties of the materials themselves, the most obvious difference seems to be whether or not they are kept reasonably dry.

This dependence on moisture content suggests a second method of achieving the objective of predicting deterioration: first, to determine the relation-

¹ Meteorologist, Division of Building Research, National Research Council of Canada, Ottawa, Ont., Canada.

ship between weather and the changes in moisture content of the material, and second, to use the weather observations at any site where they are available to predict moisture content and hence deterioration.

The main advantage of this approach is that, once the necessary relationships have been determined, deterioration can be predicted for thousands of weather stations where 20 to 30 years of weather records are available.

The main disadvantage is that it is difficult to establish the necessary relationships because they are usually very complex and often not well understood.

A few examples are presented of weather analyses that have been carried out based on very simple assumed relationships. Some of the more recent publications in Canada that would be of value are mentioned, as well as the kind of information that could be made available if required for further analysis.

Weather and Water Content

The relationship between the weather and the water content of an exposed building element depends on so many factors that it is usually impossible to solve the problem completely. Simple assumptions might provide an approximate answer. For example it might be assumed that the deleterious effect of the weather is proportional to the amount of rain and also to the strength of the wind, and therefore proportional to their product. But what time scale should be used? The product of the normal annual rainfall and the normal annual mean wind speed is one index that has proven useful.

Figure 1 shows the driving rain index in metres squared per second calculated from normal annual values for Great Britain and Ireland [1].² A more recent and detailed map was published by Lacy in 1976 [2]. However, both maps indicate severe conditions near the west coasts of Ireland, Scotland, and Wales.

Figure 2 is a similar map for Canada showing severe conditions near both east and west coasts [3].

Another way of presenting driving rain indexes is to draw "roses" with the lengths of the lines proportional to the indexes for those directions. Figure 3 shows that most of the driving rain in Great Britain comes from the south or southwest [1].

It seems obvious that a better idea of the problem would be obtained by computing indexes for each month and basing the computations only on those days or hours when rain was actually falling instead of using the mean wind speed for the whole month.

Figure 4a is based on the product of the rainfall and mean wind speed for those days when there was a measurable amount of rain at Toronto Interna-

²The italic numbers in brackets refer to the list of references appended to this paper.

FIG. 1—Driving-rain index in square metres per second for Great Britain and Ireland (Ref 1).

FIG. 2—Driving-rain index in square metres per second for Canada (Ref 2).

FIG. 3—Driving-rain roses for Great Britain (Ref 1).

FIG. 4—Driving-rain intensity at Toronto International Airport—shading and numbers indicate the severity increasing from 1 to 9. The units in a and b are different and hence the severity scales are not comparable. (a) Based on the product of daily rainfall and mean wind speed, and (b) based on the sum of hourly wind speeds during periods of rain.

tional Airport in a 5-year period. Figure 4b is based on the total number of miles of wind during periods of rain at Toronto International Airport in a 16-year period.

The two are not strictly comparable because rainfall intensity was unavailable on an hourly basis. However, they should both indicate the prevailing directions of driving rain and the months when it is a serious problem. The differences are much greater than expected and suggest that we should be very cautious about applying results of such analyses and even more cautious about analyses based on monthly or annual averages.

A second example is the relationship between the deterioration of masonry and the freezing of wetted materials. It is assumed sometimes that the number of cycles of freezing and thawing are an indication of the severity of the climate in this regard. There are at least three things wrong with this assumption:

1. Temperatures only slightly below 0°C may not freeze the water in small spaces.
  2. The temperature of the masonry may be different from the air temperature.
  3. The masonry may be dry during some cycles and hence not affected.
- If water in masonry freezes at a temperature a few degrees below 0°C then cycles above and below that temperature could be counted. This can be done easily if the freezing point of the water is known.

The assumption that the masonry temperature is generally the same as air temperature poses a real problem. The temperature of the outside surface of a well insulated wall facing north may follow the air temperature fairly closely. The temperature of a south-facing wall, on the other hand, may rise above freezing every sunny day even if the air temperature remains well below freezing for a few weeks. This is probably the most important reason for discarding the idea of counting freeze-thaw cycles of air temperature.

Finally, the question of whether the wall is wet when it freezes can only be answered by studying the physical properties, orientation and shelter of the wall, and the *sequence* of the weather. The problems arising when the sequence of the weather is important will be considered later.

These are examples of what might be considered a first step in correlating weather and deterioration. They are based on simple and obvious assumptions and cannot be expected to provide accurate quantitative results. The necessary climatological statistics also are very simple: the number of occurrences per year or the sum or average of one or two elements.

A third example is given to show that more accurate and reliable relationships will have to be based on a better understanding of the quantitative effects of weather elements on the building materials. The following example is based on research work at the Division of Building Research.

The corrosion of metals accelerates rapidly above some critical humidity at which the metal surface becomes wet enough to initiate chemical processes.

Sereda [4] defined the time-of-wetness as the interval during which the electrical potential developed between platinum and zinc exceeded 0.2 V. This time-of-wetness correlated adequately with the corrosion of steel, copper, and zinc for standard sized specimens under specified exposure conditions.

As mentioned in Ref 4, Guttman showed that the time-of-wetness measured in this way corresponded to the time during which the relative humidity of the air exceeded 86.5 percent. Sereda measured time-of-wetness at a number of exposure sites and compared the results with humidity measurements. He found the critical relative humidity to be in the high 80's at coastal stations and in the low 80's at inland stations.

If weather observations are to be used to predict corrosion rates at locations far from exposure sites, then frequency distributions of relative humidities are required. Figure 5 shows the accumulated percentage frequencies of relative humidity for 15 Canadian weather stations [4]. If the critical humidity is known, the approximate time-of-wetness for any of these locations under standard exposure conditions can be determined from this graph.

The results of this study of the corrosion of metals apply to specimens exposed under standard conditions. It should be realized that specimens exposed at a different slope or aspect, or sheltered from rain, sun, or wind might corrode at significantly different rates.

Metals and other materials that form part of a building will be affected not only by the weather created by their particular exterior exposure, but also by conditions of temperature and humidity within the building and by the physical and possibly the chemical properties of adjacent materials in the structure. Therefore, it is often advisable to study the deterioration of specimens under standard exposure conditions first, and then relate these results to the deterioration of the same material under the conditions of actual use in the building.

Frequency Distributions

A little more should be said about frequency distributions. Before about 1950 climatological statistics consisted mostly of computing the sums or averages of various elements and recording the record high and low values. The number of days with frost, gales, or thunderstorms also was recorded but not the number of days or hours with temperatures or winds above or below other values.

When punched cards and card sorting machines became available it was feasible to count the number of hours, for example, at each degree of temperature. In 1952 the frequency distribution of hourly air temperatures in January was used to select winter design temperatures for sizing heating systems for buildings.

In 1960 frequency distributions for both wet- and dry-bulb temperatures

FIG. 5—Cumulative frequency of relative humidity in the atmosphere for Canadian stations (Ref 4).

were published for 33 Canadian stations for the four summer months [5]. In the last 10 years frequency distributions of wet- and dry-bulb temperature and wind speeds have been published for every month for over 100 Canadian stations. Other distributions could be published if it is shown that a real need exists. The distribution of relative humidities mentioned above is one of the few examples of special analyses for durability studies in Canada.

Although the use of SI units is being promoted, frequency distributions of weather elements in those units may be impractical or misleading. Until recently hourly temperatures in Canada were recorded to the nearest $1/10^{\circ}\text{F}$, but the values on punched cards are rounded to the nearest whole degree Fahrenheit. This means that each reading has already been assigned to a class with a range of 1°F . These classes can easily be combined to form 2-degree or 3-degree classes but they cannot be combined to form 1.0°C or 1.8°F classes. If the Fahrenheit temperatures are converted to Celsius and then rounded to the nearest degree the classes that seem to have ranges of 1°C will actually have ranges of 0.56 or 1.11°C or 1 or 2°F . It is difficult to use a distribution in which the class ranges are not all the same. It is much better to work with a distribution in the original units and convert them only after the analysis is complete.

A few examples of attempts to predict the durability of building materials from weather observations have been given. The next step would seem to be to improve our knowledge of the relationship between the weather and the deterioration of a material. This could be done in the laboratory under controlled conditions, or at exposure sites using the natural weather. Probably both methods should be used. If possible, outside exposure sites should be as close as possible to first class weather stations, for two reasons. First, if the results are to be used to predict durability elsewhere the weather should be observed with the same instruments and in the same way as it is across the country. Second, the staff at a first-class weather station is more reliable than most recording instruments. There are many stations in Canada and probably also in the United States and other countries where the staff have not missed a single hourly weather report in over 10 years.

Weather Observations

If more accurate relationships between weather and deterioration can be found then it is most likely that more complex weather analyses will be wanted. It may be worthwhile to list some of the weather information readily available and some of the analyses that could be made available. Canada will be used as an example. There are now over: 2500 weather stations that measure precipitation daily or oftener; 2100 that measure daily maximum and minimum temperatures and precipitation; 200 that measure hourly winds; 160 that measure hourly temperature, humidity, cloudiness, etc.; 50 that measure solar radiation.

The simplest weather statistics such as average temperatures (based on daily maximum and minimum) and totals of rainfall and snowfall are readily available for over 2000 stations.

As mentioned earlier the average is not enough for some studies but a frequency distribution may be. The frequency of winds from each direction is available for about 200 stations and the frequency for several wind speed ranges for 120 stations. Frequency distributions of both wet- and dry-bulb temperatures have also been tabulated for each month for 120 stations.

If they are needed, other frequency distributions could be obtained from the weather observations at these stations. More complex analyses are also possible, such as the distribution of winds by direction during periods of rain which was used as an index of driving rain. Another possibility is a two-dimensional distribution such as a table showing the frequencies of all combinations of wet- and dry-bulb temperatures [5].

There is another way in which weather observations can be used when the *sequence* of weather events is important. In some deterioration processes the rate of change of temperature is important. As already mentioned the wetness of a wall when it freezes affects its response. Long ago, when mechanical adding machines were called digital computers an attempt was made to predict the durability of masonry by studying the weather day by day. In particular the minimum temperature in the two days following each rainstorm was tabulated and the number and severity of freezing periods noted. With today's computers the same approach could be applied to hourly weather observations using more complex models of moisture absorption and energy exchanges at the wall surface.

Heating and air-conditioning engineers have been using hourly weather observations to predict the energy requirements of buildings. The calculations are rather complicated and 1 year, or 8760 h, takes quite a bit of computer time. To get a reasonably reliable average for the annual fuel bill the calculations should be repeated for at least 10 years and preferably 20 or 30.

To reduce the necessary computer time there have been attempts to compile hourly weather data for a "typical year." Two promising methods have been proposed but neither has been used at more than one station so far. These typical years of hourly weather reports could also be very useful in deterioration studies [6, 7].

The duration of bright sunshine has been measured at quite a few stations for many years but measurements of the intensity of solar radiation are less common. Canada now has about 50 stations measuring solar radiation on a horizontal surface but many of the record periods are rather short. These measurements can be used to calculate heat gains. If you are concerned about radiation in certain wavelength bands because of its direct effect on materials, you should urge your meteorological service to start making such measurements.

The durability of some building materials depends very much on the

amounts of certain chemicals in the atmosphere. These atmospheric pollutants are not measured at the regular weather stations, but in recent years a number of special air pollution stations have been set up. The main interest seems to be the possible effects of pollutants on human beings, but the observations also should be applicable to the durability of building materials.

Concluding Remarks

In the past climatologists have compiled voluminous tables of mean values or record extremes or annual totals of many weather elements. Some attempts have been made to correlate these simple statistics to the deterioration of building materials, with only moderate success.

When punched cards and sorting machines became available climatologists were able to provide frequency distributions of almost any weather element. Wind and temperature frequency distributions were published. A few special distributions were prepared for correlation with deterioration problems but much more could be done.

Modern computers can handle numerical solutions of simultaneous differential equations. Hourly weather observations for hundreds of stations are available on magnetic tape. If the relationships between deterioration and the weather can be established at a few locations then they can be extended to all locations in the extensive weather network around the world.

Acknowledgments

The author would like to thank G. P. Williams and P. J. Sereda for their comments, and R. E. Lacy for permission to use two of his maps.

References

- [1] Lacy, R. E., "An Index of Exposure to Driving Rain," Building Research Station Digest 127, March 1971.
- [2] Lacy, R. E., "Driving-Rain Index," Building Research Establishment Report, Department of the Environment, London, 1976.
- [3] Boyd, D. W., "Driving-Rain Map of Canada," Technical Note No. 398, Division of Building Research, National Research Council of Canada, May 1963.
- [4] Sereda, P. J., in *Corrosion in Natural Environments*, ASTM STP 558, American Society for Testing and Materials, 1974, pp. 7-22.
- [5] Boughner, C. C., "Percentage Frequency of Dry- and Wet-Bulb Temperatures from June to September at Selected Canadian Cities," Canadian Meteorological Memoirs No. 5, Meteorological Branch, Department of Transport, Toronto, 1960.
- [6] Crow, L. W., "Summary Description of Typical Year Weather Data, Chicago Midway Airport," ASHRAE Research Project RP-100, Report No. 80, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Feb. 1970.
- [7] Degelman, L. O., "A Weather Simulation Model for Building Energy Analysis," Department of Architectural Engineering, Pennsylvania State University, University Park, Pa., Oct. 1974.