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Relative Humidity: Its Importance, Measurement and Control in Museums

K.J. Macleod

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Abstract

Moisture in the atmosphere plays a substantial role in the deterioration of works of art and museum objects. In this bulletin the relative humidity or RH, a measure of the moisture content of air, is described and the part it plays, sometimes in conjunction with atmospheric pollutants, is discussed in terms of the cracking and flaking of paint layers, the shrinking of wood, the cockling of parchment and paper, the corrosion of metal, the growth of moulds and fungi, etc.

A range of acceptable RH values is suggested for museums. Some of the equipment available for monitoring relative humidity is described and the techniques available for controlling it are briefly discussed.

Résumé

L'humidité de l'air joue un rôle important dans la détérioration des oeuvres d'art et des pièces de musée. Le présent bulletin définit l'humidité relative (ou H.R.). mesure de la teneur en vapeur d'eau de l'air, et explique comment elle contribue, parfois conjointement avec des pollutants atmosphériques, à fendiller et à écailler les couches de peinture, à contracter le bois, à faire gondoler le parchemin et le papier, à corroder le métal, à provoquer de la moisissure et la croissance de fongus, etc.

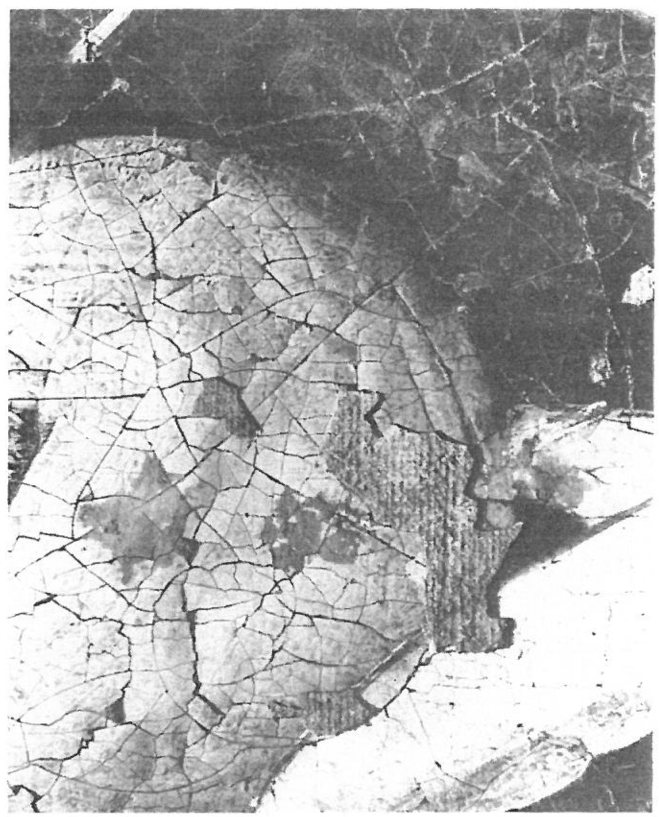
Il donne en outre l'échelle de l'H.R. acceptable dans les musées. Il décrit également certains des appareils utilisés pour mesurer l'humidité relative et explique brièvement les méthodes de réglage disponibles.

1. Introduction

The deterioration of works of art and museum objects starts at the time such things are made and proceeds through their lives. Iron objects rust (a special case of the more general problem of the corrosion of metals), paintings develop cracks and the paint layer may flake off, wood warps, paper cockles and discolours, both textiles and paper rot, leather decays, etc. Such deterioration is natural in the sense that it is the response by which such artifacts attain a state of physical and chemical equilibrium with their immediate environment. For example, the natural or equilibrium state of iron in the atmosphere is as the oxide of which rust is composed. Thus, in time all iron artifacts must turn to rust, but this tendency becomes rapid when the atmospheric moisture content increases. Porous materials such as wood, when brought from a dry to a humid atmosphere will adsorb water vapour and swell until a new equilibrium is reached.

Our modern industrial environment contains substantial amounts of sulphur dioxide which is evolved in the production of many metals from their ores and in the burning of fuels such as coal and oil. In the presence of air and water the sulphur dioxide forms sulphuric acid. Where materials known as catalysts are present this formation of sulphuric acid is greatly speeded up; iron salts and oxides function as catalysts for this reaction. The sulphuric acid formed will cause the deterioration of most materials. Paper will discolour and become brittle; the long molecules, of which fibrous materials such as papers and textiles are composed, are broken under the action of the acid and the material loses its strength; leather will become weak and powdery; marble is transformed and may disintegrate in the process. In the presence of light many other degradation reactions are initiated.

Humidity fluctuation can be especially damaging to composite objects. For example, the wooden supports of panel



Damage to painting resulting from improper humidity control. The initial cracking of the paint film has led to its lifting and the eventual loss of paint. NCRL study collection. The National Gallery of Canada, Ottawa.

paintings alternately swell and contract as the relative humidity of the atmosphere increases and decreases. This movement cannot be accommodated by the paint film (particularly by older more brittle films) and the paint will crack and eventually flake off.

Biological processes are also influenced by RH. One such problem associated with excessive humidity is mould growth. Fungi thrive in damp atmospheres and under such conditions mildew will form rapidly on materials, such as leather, paper, textiles, from which they can obtain nourishment. Their presence may result in staining of such materials and in extreme cases destruction of the object.

These are only a few of many examples that could be given to illustrate the influence that moisture in the atmosphere, either alone or in conjunction with light or with other atmospheric constituents, may exert on the deterioration of a wide range of artifacts. Before proceeding further, however, it is necessary to define more precisely what we mean by humidity and examine the concept of relative humidity.

2. Definition of Relative Humidity

Imagine a volume of air, say one cubic foot or one cubic metre, at normal atmospheric pressure from which we will remove all of the water vapour dissolved in it. This might be done by greatly lowering the temperature and literally freezing out the water or by passing the unit volume of air over a drying agent (dessicant). The water so removed could then be weighed and we would know the concentration of water vapour, in terms of pounds per cubic foot or grams per cubic metre, in the original sample of air. This concentration is called the absolute humidity. The absolute humidity can also be expressed in terms of a unit weight of air: pounds water per pound of air or grams water per kilogram of air. This latter method of expressing the absolute humidity is common in much of the conservation literature as in Plenderleith and Philippot's article on museum climatology[1].

The types of deterioration which we have discussed do not correlate with the absolute humidity, however. It turns out that whether or not an artifact takes up or gives off moisture depends not so much on the absolute humidity as it does on the capacity of that air to hold additional moisture. That capacity unlike absolute humidity depends on the temperature of the air. It is therefore necessary to define a somewhat more complex concept which takes temperature into account, the relative humidity.

Consider a cubic metre of air in a closed container at a temperature of 20°C (68°F) and suppose this cubic metre of air contains 9 grams of water vapour; the absolute humidity is 9 g/m^3. Let us suppose we then open a tap and allow 3 grams of water to flow into the container, we will find that this water will all evaporate and the absolute humidity becomes 12g/m^3. If we had let 8 grams enter, all of it would also have evaporated (absolute humidity 17g/m^3) but if we had let more than 8 grams enter, only 8 grams would have evaporated and the rest would have remained liquid. For example, if we had added 10 grams of water, 8 grams would evaporate to give an absolute humidity of 17 grams per cubic metre and we would have a puddle with 2 grams of water at the bottom of the container. At 20°C air can hold only 17 grams of water vapour per cubic metre and there is no ordinary means by which we can add more than this amount of moisture. The air under these conditions is at its maximum absolute humidity and is said to be saturated.

The relative humidity (RH) is defined as the ratio, expressed as a percent, of the absolute humidity of sampled air to that of air saturated with water at the same temperature:

$$RH = \frac{\text{absolute humidity of sampled air} \times 100}{\text{absolute humidity of saturated air}}$$

For example, the relative humidity, or RH, of the air we started with in the example above was

$$\frac{9}{17} \times 100 = 53\%$$

After adding the 3 grams of water it would have been

$$\frac{12}{17} \times 100 = 71\% \text{ RH}$$

At saturation the relative humidity would, of course, be 100%. Table 1 gives some values of the absolute humidity for saturated air at different temperatures.

The amount of moisture that air can hold increases with increasing temperature.

TABLE 1

Absolute Humidity of Saturated Air at Different Temperatures

Temperature		Grams of water per cubic metre of air
°C	°F	
-50	-58	0.04
-40	-40	0.12
-30	-22	0.34
-20	-4	0.90
-10	14	2.1
-5	23	3.2
0	32	4.8
5	41	6.8
10	50	9.4
15	59	13.
20	68	17.
25	77	23.
30	86	30.
35	95	40.
40	104	51.

Absolute humidity values in column 3 were calculated from vapour pressure data given in the Handbook of Chemistry and Physics, 50th edition (The Chemical Rubber Company, Cleveland, Ohio, 1969).

Therefore, a given absolute humidity corresponds to a smaller relative humidity as the temperature of the air is increased. For example, let us consider the sample of air discussed above which contained 9 grams of moisture per cubic metre. We have seen that at 20°C it had a relative humidity of 53%. At 25°C (77°F), air can hold a maximum of 23 grams of water per cubic metre so that if we were to warm our sample of air from 20°C to 25°C the relative humidity would drop from 53% to

$$\frac{9}{23} \times 100 = 39\%$$

Continued increase in temperature would result in further lowering of the RH. Now we can see why indoor air in winter can have such a low relative humidity. The air out-of-doors might be at -20°C (-4°F) and even if the relative humidity is 100% the absolute humidity is only 0.9 grams per cubic metre. If then that air is taken indoors and heated to 20°C (68°F), the relative humidity will only be

$$\frac{0.9}{17} \times 100 = 5\%$$

Of course, the opposite can also happen so that if the temperature is lowered as it may be at night, the relative humidity will rise. Thus if a room is at 25°C (77°F) and the relative humidity is 80% the absolute humidity will be approximately 18 grams per cubic metre. Should the temperature drop to about 21°C (69.8°F) the relative humidity will rise to 100%. Should the temperature drop below 21°C, even slightly, the air will be unable to contain the entire 18 grams of water vapour per cubic metre and water will condense out in the form of a mist or droplets. Thus the temperature at which the RH is 100% is called the dew-point. Such condensation can be observed when you blow on a cool mirror. There is a danger that when an artifact is brought suddenly from a cool environment to a warm room that the air in its immediate vicinity will be cooled sufficiently that the relative humidity will reach 100% and moisture will condense on the surface of the artifact.

It should be noted that the absolute (and hence relative humidity) is almost totally insensitive to atmospheric pressure. One may, therefore, ignore the effect on RH of changing pressure such as during airplane transport of an object or its exhibition at a museum at high altitude. Changes in temperature, however, cannot be ignored.

3. Behaviour of Materials toward Humidity

Unlike the absolute humidity, the relative humidity can be correlated with the uptake of moisture by various substances. At a given RH wood, paper, leather, textiles etc., will attain an equilibrium, specific for each material, at which they will have a constant moisture content. In practice certain complexities referred to as "hysteresis effects"* should be considered but we shall ignore them here. If the relative humidity were to increase, the moisture content of the material would rise until a new equilibrium moisture content was reached after which the moisture content would again remain constant. On the other hand, if the relative humidity were to decrease, the moisture content of the artifact would also decrease down to a new equilibrium value. To illustrate this concept Figure 1 shows a graph of equilibrium moisture content versus relative humidity for a few textile fibres. Figure 1 illustrates the type of relationship (i.e. the general shape of the graph) that exists between equilibrium moisture content

*Hysteresis refers to the incomplete reversibility of adsorption curves. As one increases the RH the equilibrium moisture content increases. If one then begins to decrease the RH it is found that the equilibrium moisture content is higher for any given RH than it was during the period of increasing RH. The object does not quite return to its original state.

and relative humidity. It also illustrates that even among textiles there are differences between the amount of moisture which a particular fibre such as cotton will adsorb at a given relative humidity and that which another fibre such as nylon will adsorb at the same relative humidity. Different materials behave differently with respect to adsorption just as they differ with respect to other properties. Additional graphs could be made for other substances such as wood or leather which would be similar in shape but again would differ in actual amounts. Wood shows rather high adsorptions, not unlike the viscose rayon in Figure 1. On the other hand, plastics and metals show negligible adsorption even at the highest relative humidities. With these non-porous materials adsorption is restricted to the surface and, although the surface moisture can be sufficient at even 45 to 50% relative humidity to cause corrosion in the case of metals, it still represents a small percentage of the total weight of the object. These non-porous materials, therefore, show negligible dimensional changes as a result of changes in relative humidity. Rocks such as limestone may be porous but because of their nature they also show

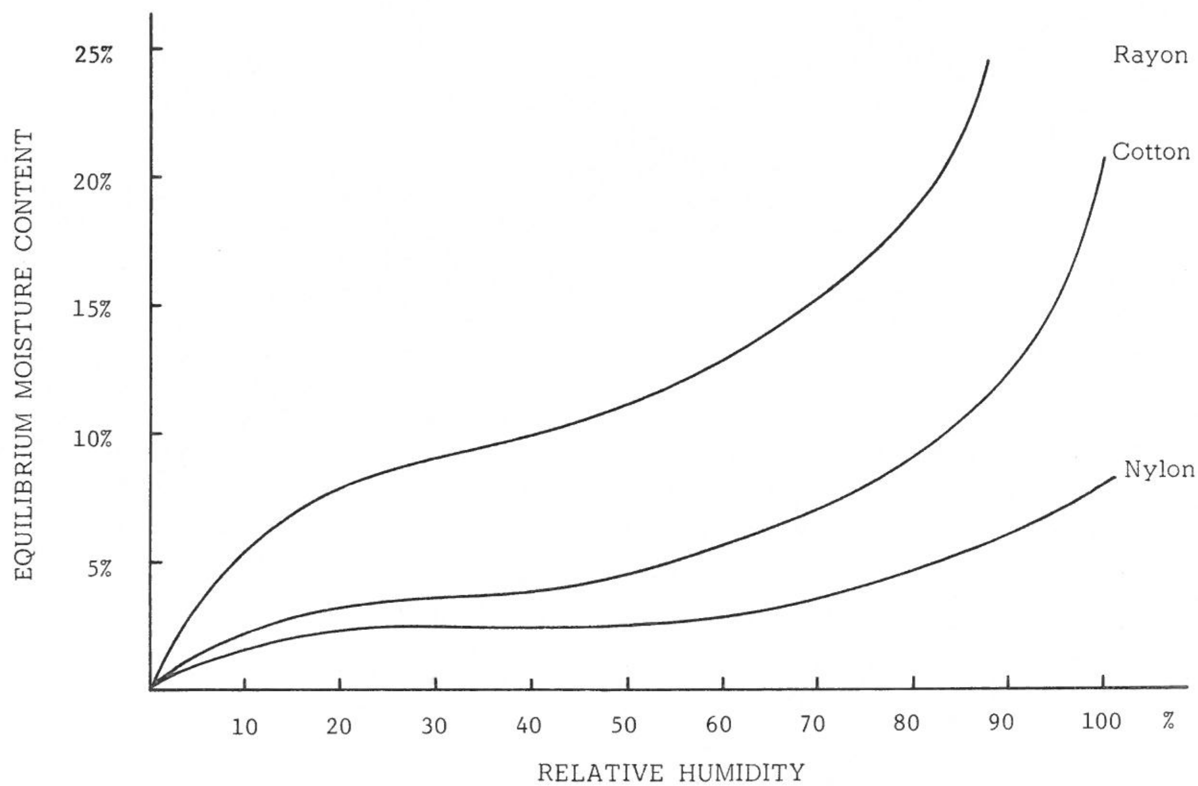


Figure 1 - Effect of relative humidity on the absorption of water vapour.

very little in the way of dimensional change as a result of high relative humidity but the freezing of water in the pores of such artifacts, as might happen if exhibited out-of-doors in winter, can cause spalling of the rock. So-called hygroscopic materials such as wood, paper, leather, textiles etc., swell as they take up moisture and shrink as they give up moisture, and pronounced dimensional changes can occur as such materials seek to attain their equilibrium moisture content in an environment with a changing relative humidity. It is these dimensional changes which give rise to the problems listed in the introduction.

The extent of dimensional changes with change in relative humidity is illustrated in Figure 2 which illustrates the changes in length of an oil painting that formed part of the exhibition, Progress in Conservation. The data does not represent equilibrium conditions.

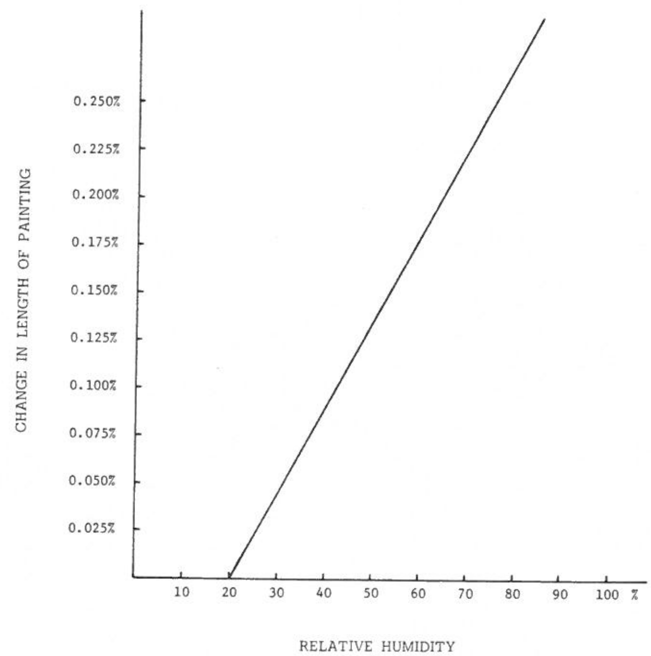
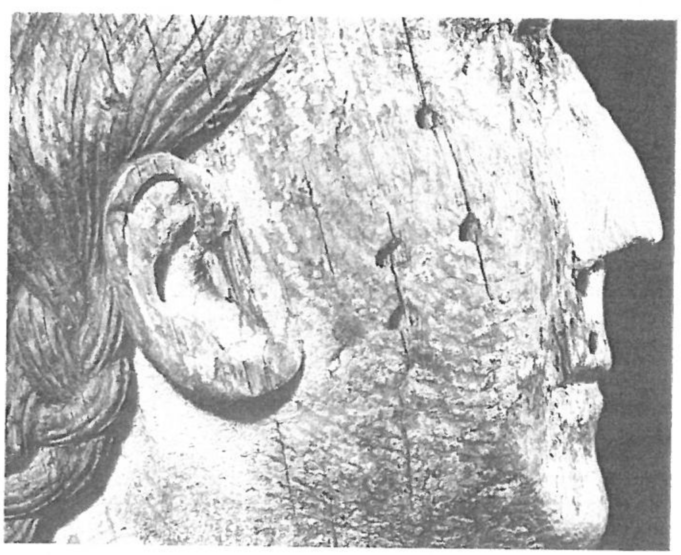


Figure 2 - Change in length of an oil painting with change in the relative humidity.



Detail of polychrome sculpture showing splitting of the wood and paint loss. Collection Musée du Québec.

4. Optimum Relative Humidity Ranges

When we come to consider the best relative humidity at which to maintain a museum collection, it is necessary to consider the nature of the collection and the factors causing deterioration. Mould growth requires a high humidity. At temperatures between 16° and 25°C (60° and 75°F) it has been claimed that the propagation of mould requires a relative humidity in excess of 68%. We believe that even at 65% RH some mould species may propagate; this provides us with an upper tolerable level at which to maintain a museum RH. A practical upper limit is thus 65% relative humidity. Even at this level there is some risk of mould. If this value is exceeded a considerable risk of mould infestation is incurred; the more it is exceeded, and the larger the exposure, the greater the risk.

Another way of looking at the problem of setting acceptable RH ranges is to consider wooden artifacts. Such objects have likely been made from air seasoned wood and it is unlikely that such wood contained much less than 9 or 10% moisture at the time of fabrication. It may have, depending on the wood and on whether the object came from a particularly arid region, but the majority of wooden objects will have originally had at least 9 or 10% moisture. Ideally, a wooden object should be maintained throughout its life at a moisture content similar to that at the time of its fabrication because it is only at that condition that the joins and fitting of the parts will be exactly as the artisan intended. If we accept 9 or 10% moisture content as a reasonable lower limit for the original moisture content of most wooden artifacts then we should place a lower limit of about 45% on the relative humidity of museums since that RH corresponds to an equilibrium moisture content of 9 to 10% in wood. We are here suggesting a lower general limit and, in so doing, do not mean to imply that every wooden object should be kept in a 45% RH environment. There may well be specific objects in the collection that require particularly rigid humidity control at a different value because of their value and their particular history.

Considering the collection in isolation we have then arrived at a range of relative humidity values within which we should aim to maintain a general collection - i.e. between 45 and 65% RH. However, the available humidification equipment and the particular construction of the museum building may not permit one to maintain these conditions under the extremes of a Canadian climate. However, if the humidity cannot be controlled and it rises above 65% in summer and drops below 45% in winter, we may expect damage to occur to the artifacts. Even within the range 45 to 65% RH rapid variations can cause damage to particularly sensitive articles. The temperature should be maintained between 19 and 22°C (66° - 72°F). Plenderleith and Werner recommend an unvarying relative humidity of 58% at 17°C (63°F) for valuable easel paintings. Practicality however dictates that, for the general collection, we accept a range of relative humidity values and treat the ultra-sensitive article as an exception which can be provided for by such measures as a specially designed case in which a very constant relative humidity can be maintained. Even if the expensive air conditioning equipment were available to provide relative humidities in excess of 50% throughout the building, there are not many buildings in Canada that could survive such treatment through many winters. We therefore have to accept in most cases that the relative humidity in winter will be lower than in summer, but we should aim to keep it above 45% and we should try to ensure a gradual adjustment from summer to winter conditions and vice versa. Clearly the smaller we can keep the seasonal variation the safer will be the collection. Any daily variations should be much smaller than the seasonal variations. If even 45% RH is unattainable in mid-winter because of the nature of the building then one may have to accept a lower minimum RH. If this is the case then one should similarly decrease the maximum permissible relative humidity. A range of 35 to 55% RH might be an acceptable compromise. The imperative is to keep the range of seasonal variations as small as possible.

5. The Measurement of Relative Humidity

In defining absolute humidity, we have suggested that air might be passed over a dessicant which would adsorb all of the moisture from a known volume of air and permit the moisture so adsorbed to be weighed. This would give us the absolute humidity averaged over the length of time required to make the measurement. Comparison with a table giving the absolute humidity at 100% RH for the temperature in question would permit calculation of the relative humidity. Although sound in theory the laboriousness of making measurements in this way renders it impractical for almost all purposes, an exception being certain scientific calibrations.

A. Dew-Point Hygrometers

As we cool air the relative humidity increases until a temperature (the dew point) is reached at which the air is saturated with moisture, (i.e. RH equals 100%) and liquid water just begins to condense out. The higher the initial relative humidity of the air, the less it will have to be cooled for condensation to occur. This principle can be used to devise an instrument for the measurement of relative humidity that is termed a <u>dew-point hygrometer</u>. Dew-point hygrometers consist of various mechanical devices for cooling a sample of air until condensation occurs and for measuring this dew-point temperature. By consulting tables or charts the relative humidity can be determined from the dew-point temperature for the particular environment from which the sample was taken. It is an instrument that, if well designed and in the hands of a skilled operator, will provide the very highest accuracy but it is not the type of instrument that would be routinely used in a museum or art gallery. Measurement is time-consuming and requires some considerable care and skill. Such dew-point hygrometers are meant for single determinations and cannot be readily adapted to situations requiring recording. On the other hand, the dew-point hygrometer requires a very small sample which may lend it to special situations as, for example, the measuring of the relative humidity within a confined volume such as the interior of a picture frame. A simple dew-point hygrometer could be purchased for less than $50, but more automated dew-point hygrometers are available which would overcome some of the limitations for routine use. For example, the Environmental Equipment Division of the EG and G Company has one employing thermoelectric sensing of the dew-point which costs about $1000. Somewhat less sophisticated are instruments marketed by scientific survey houses such as Canadian Laboratory Supplies for about $400. However, at these prices they are probably too expensive compared with psychrometers for most museum use.

B. Psychrometers

Psychrometers consist of two thermometers, not unlike the dew-point hygrometer in this respect. One measures the room temperature. The other is sheathed in cotton which must be kept moist. The moisture will evaporate and cool the thermometer below the indication on the dry bulb. If the environment is at 100% relative humidity, obviously no evaporation can occur and there will be no difference in the readings of the two thermometers. The drier the environment, the more rapidly the water will evaporate, the cooler the wet bulb will get and the greater will be the difference between the two thermometer readings. A chart or table is supplied by the instrument manufacturer relating this temperature difference to the relative humidity. An example is shown in Table 2. A complete table

TABLE 2

EXAMPLE OF A PSYCHROMETRIC TABLE

Relative Humidity Expressed as Per Cent for Centigrade Temperatures

Air temperature (t)	Depression of wet-bulb thermometer (t-t')														
Degrees Celsius	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4	1.5
0	98	96	94	93	91	89	87	85	83	81	80	78	76	74	73
1	98	97	95	93	92	90	88	86	85	83	81	80	78	76	75
2	98	97	95	93	92	90	89	87	85	84	82	81	79	78	76
3	98	97	95	94	92	91	89	88	86	84	83	82	80	78	77
4	99	97	96	94	93	91	90	88	87	85	84	82	81	79	78
5	99	97	96	94	93	91	90	88	87	86	84	83	82	80	79
6	99	97	96	94	93	92	90	89	88	86	85	84	82	81	80
7	99	97	96	95	93	92	91	89	88	87	86	84	83	82	80
8	99	97	96	95	94	92	91	90	88	87	86	85	84	82	81
9	99	98	96	95	94	93	91	90	89	88	87	85	84	83	82
10	99	98	96	95	94	93	91	90	89	88	87	86	84	83	82
11	99	98	97	95	94	93	92	91	90	89	87	86	85	84	83
12	99	98	97	96	94	93	92	91	90	89	88	87	86	85	84
13	99	98	97	96	95	93	92	91	90	89	88	87	86	85	84
14	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85
15	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85
16	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85
17	99	98	97	96	95	94	93	92	91	90	89	89	88	87	86
18	99	98	97	96	95	94	93	92	92	91	90	89	88	87	86
19	99	98	97	96	95	95	94	93	92	91	90	89	88	87	87
20	99	98	97	96	96	95	94	93	92	91	90	89	89	88	87
21	99	98	97	97	96	95	94	93	92	91	90	90	89	88	87
22	99	98	97	97	96	95	94	93	92	92	91	90	89	88	87
23	99	98	97	97	96	95	94	93	93	92	91	90	89	89	88
24	99	98	98	97	96	95	94	94	93	92	91	90	90	89	88

is much larger and a person should use the one supplied by the instrument manufacturer.

Errors can occur in measurements made by a psychrometer as a result of differences in the evaporation rate from the wet bulb that are caused by small air movements. To avoid these difficulties, it is necessary to maintain an air flow over the bulbs in excess of a critical value. In the Assman-type psychrometer, this is accomplished by a small electrically driven fan. In the sling psychrometer, this is done by whirling the whole psychrometer assembly around a handle at a given rate and for a given period of time. The accuracy of a well constructed instrument of the Assman type is greater than those of the sling type but sling psychrometers are cheap. With a good Assman psychrometer, the relative humidity measurement can be accurate to within two units of percent.

Psychrometers are available which record the results on a continuous basis; they incorporate either strip or circular charts which simultaneously record both wet and dry bulb temperature.

As with any instrument, the results obtained will depend greatly on the care taken in its use; the manufacturer's recommendations should be carefully followed. In particular, attention must be given to the wicks or sheaths which should be closely fitted to the thermometer bulb, adequately wetted with distilled water and kept free of salts. Accurate readings of the temperature are required if the measured RH is to be accurate. As may be seen in Table 2, if the room temperature is 20^{o}C, and one reads 1.4^{o} as the difference between wet and dry bulb temperatures, the relative humidity is 88%. If 1.5^{o} were read instead, the RH would be 87%. Thus a 0.1^{o} error in determining the temperature difference will result in an error of one unit of percent in the RH measurement. Obviously, the thermometers must be precise and they must be read with care. A sling psychrometer can be purchased for under $25; Assman types cost about $100.

C. Hair Hygrometer

Probably the best known hygrometer is the hair hygrometer, versions of which are offered for sale in many department stores for home use. The principle behind their operation is, as we have seen earlier, that a hair, or bundle of hair fibres, will lengthen as the relative humidity increases and shorten as the relative humidity decreases. This change in the length of the hair is transmitted to a pointer or to a recorder pen.

Hair hygrometers are not as accurate as a psychrometer or a dew-point hygrometer and they may take up to one half hour to fully respond to a change in the relative humidity. However, they are cheap, they may be read directly in relative humidity and can be used by anyone. The usual measurements in a museum do not necessarily require great accuracy. We frequently want to know whether the museum atmosphere is within the acceptable RH range and the local variations within many museum buildings may well be as great as 10%. For such museums, the hair hygrometer may well be satisfactory providing it is used with respect for its limitations. It should be calibrated every month or so against a reliable dew-point instrument or a psychrometer. Hair hygrometers have their best accuracy in the range between 30 and 80% RH. The price of the simplest hair hygrometers is $10 or less.

D. Coloured Salts

Various cobalt salts such as cobalt thiocyanate have a colour that depends on the relative humidity. Paper that has been impregnated by such a salt can be placed in the environment under test. The colour, which varies from blue to pink, can be compared with standard colours to indicate the approximate relative humidity. They are not particularly accurate (certainly the relative humidity cannot be assessed to better than 5% by such a technique) and they do not lend themselves to measurements in large rooms. They are, however, inexpensive and can be used to advantage in confined cases.

E. Miscellaneous Hygrometers

There are hygrometers available based on other physical and chemical principles. The diffusion hygrometer depends on the pressure difference developed across a membrane on one side of which is a saturated atmosphere (obtained by partly filling the chamber with distilled water) and on the other side of which is the atmosphere under test. The greater the pressure difference, the lower the relative humidity.

The capacitance hygrometer incorporates a hygroscopic dielectric so that the capacitance which is monitored by an associted metre is a measure of the relative humidity.

Other hygrometers measure the resistance of a humidity-sensitive resistor.

F. General Considerations

The Canadian Conservation Institute will in the near future be issuing recommendations on specific environmental monitoring equipment. For the present, we will restrict ourselves to general observations. Every museum, no matter how small, should be able to afford simple hair hygrometers which can be purchased for $10 or less. In fact, for the price, a few could be purchased and placed in different locations. These will indicate large changes in the relative humidity between different parts of the building and between different periods of the year. To have confidence in the actual readings, these hair hygrometers must be calibrated against a good dew-point hygrometer or psychrometer. A Bendix "Psychron" psychrometer suitable for calibrating purposes can be purchased from Fisher Scientific Co., Limited, for less than $100. Unless one is prepared to make frequent observations with the simple hair hygrometers both during museum hours and outside of them, it will be impossible to discover certain cycling behaviour in the RH. To do this conveniently, it is necessary to have a recording hygrograph. An instrument such as the thermohygrograph made by the R. Fuess Co. and sold by the Hughes-Owens Co. costs about $575. This instrument makes a continuous recording of both the temperature and the relative humidity over a 7-day period after which it is necessary to insert a new strip chart. This instrument, being of the hair type, should be calibrated against a "Psychron". Both Fisher Scientific and Hughes-Owens have outlets in many Canadian cities.

6. Methods for Controlling the Relative Humidity

In this section we will examine very quickly the type of equipment available for the control of relative humidity. It is not intended to be exhaustive but merely to give the curator an idea of what can be done. To do more would be to make this bulletin far too long and thus diminish its usefulness. Exhibition case design and museum air conditioning are topics that deserve their own bulletins and future publications from the Canadian Conservation Institute will undoubtedly include them.

The ultimate is a well designed central air conditioning system in which both temperature and relative humidity are rigidly controlled day and night, winter and summer. Systems to ensure adequate preservation of artifacts are more elaborate and expensive than those required just for human comfort. Over-dry air may have its humidity increased by passing it through a fine spray of water formed by nozzles or other mechanical means or by vaporizing water by heating. Over-humid air may be dehumidified by passing it over refrigerator coils which cool it and condense out the moisture or by passing the air through a bed of dessicant. The museum that can afford such a system will have to consult with a qualified engineer who can specify the exact requirements based on the external climate, the size and layout of the building, the quality of the water available, the way the building walls are constructed, the type of heating system, etc. Each building poses unique problems and a custom solution is required. The best solution will be achieved when it can be implemented during construction of the building or when the building can be modified to accommodate the needs of the air conditioning system. Once installed, the museum will need to employ a competent person to operate and maintain the system.

Only the more fortunate museums will be able to achieve the full environmental control that is implied in a properly designed air conditioning system. The smaller museum, however, may be able to install portable humidifiers to increase the low indoor relative humidity during the dry months of the Canadian winter. The wick-type portable humidifier will put only a few gallons of water per day into the room air and one would have to buy quite a few of them in order to do an adequate job of humidification. However, there are drum-type units retailing at less than $100 that will evaporate about 17 gallons per day. Portable dehumidifiers are also available retailing at about $150. These will remove, depending on the size, between 14 and 24 pints of water before the dessicant has to be regenerated. There are also mechanical units which remove a similar amount of water vapour by condensation; drains or trays are needed to collect the condensed water.

The number of units required will depend on a number of factors and will most readily be found by adding units until the desired humidity is achieved. It is extremely important that humidifiers and dehumidifiers be placed in storage areas; this is something that is often overlooked when cutting costs. In order to obtain satisfactory results windows should be sealed and doors kept closed. It is advisable to install automatic door closers; revolving exterior doors are also an advantage. To keep the relative humidity up in winter, avoid overheating the building. Keep the temperature as low as is comfortable, certainly below 22°C and preferably below 20°C. But above all keep the temperature and relative humidity constant. Do not let the temperature drop at night and rise during the day when the museum is open. Such daily variations can be very damaging and is therefore false economy. It is far better anyway to keep the temperature down both day and night.

In many buildings it is likely that an attempt to maintain a reasonable humidity in the interior during the coldest months of the year will lead to serious damage to the exterior walls of the building. This occurs because water vapour will diffuse through the wall from the region of high humidity inside to the low humidity atmosphere outside. In the colder regions within the wall the water vapour may condense and leach salts out of the wall. These show up on the exterior surface as a white discolouration or efflorescence. Freezing of the water or precipitation of salts within the wall can cause volume changes which shatter the brick or masonry and cause it to spall off. In the coldest periods it is quite possible for water vapour to condense even on the inside of an exterior wall with ultimate destruction of the plaster or gyproc. In the event of severe restrictions on the permissible RH levels in a building, it may, however, prove possible to house the more susceptible items of the collection in an interior room. One can then maintain the humidity of this room at the desired level, and, with an effective buffer zone of lower relative humidity between this room and the exterior walls, damage will be minimized or even prevented.

Collections will contain items whose value dictates exercise of the greatest care in their preservation. If the budget does not permit the control of the entire museum environment to the required degree, these items may be placed in sealed glass or Plexiglas cases, the environment of which can be so controlled. Silica gel can be preconditioned so that when it is kept within the case it will ensure that the desired relative humidity is maintained. (2) Preconditioned silica gel is by far the most convenient, but in its absence a saturated salt solution can be used. For aesthetic reasons, it may be desired to hide the silica gel or salt solution beneath a porous false bottom in the case. (3)

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1. H.J. Plenderleith and P. Philippot, 'Climatology and conservation in museums', Museum (Paris), xii, 4 (1960), 201-289.

2. For a discussion of case design see N. Stolow, 'Fundamental case design for humidity sensitive museum collections', Museum News (Washington), Technical Supplement No. 11, February 1966.

3. Ibid.

Bibliography

Readers who wish to pursue the subject of hygrometry to a deeper level are recommended to consult the article by H.J. Plenderleith and P. Philippot and the work edited by A. Wexler. Some of the material covered in this present bulletin is presented more briefly in the other publications.

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