Storage Climates for Musical Instruments

Author(s): Cary Karp

Source: *Early Music*, Oct., 1982, Vol. 10, No. 4 (Oct., 1982), pp. 469-476
Published by: Oxford University Press
Stable URL: https://www.jstor.org/stable/3126935

Cary Karp

Storage climates for musical instruments

Choice Obſervations about keeping a Lute.

And that you may know how to *ſhelter your Lute*, in the worſt of *Ill weathers*, (which is *moiſt*) you ſhall do well, ever when you *Lay it by* in the day-time, to put *It into a Bed, that is conſtantly uſed, between the Rug and Blanket*; but *never* between the *Sheets*, becauſe they may be *moiſt* with *Sweat*, &c.

This is the *moſt abſolute and beſt place to keep It in always*, by which doing, you will find *many Great Conveniences*, which I ſhall here ſet down.

A Caveat needfull.

Therefore, a *Bed will ſecure from all Theſe Inconveniences*, and keep your *Glew* ſo *Hard* as *Glaſs*, and *All ſafe and ſure*; only to be excepted, *That no Perſon be ſo inconſiderate, as to Tumble down upon the Bed whilſt the Lute is There*; For *I have known ſeveral Good Lutes ſpoil'd with ſuch a Trick*.

Tho. Mace, 1676.

1 Advice on the care of the lute, from T. Mace, *Musick's Monument* (London, 1676), pp.62, 64

The climatic conditions suitable for the maintenance of musical instruments, though perhaps not an entertaining subject, is one that requires understanding by anyone who owns such objects and is interested in ensuring their long-term survival. Musicians are well acquainted with instruments that have cracked, warped or suffered other damage, not as a result of incautious handling but of forces that were at work while the instrument was assumed to be in safe storage. ('Storage' is here used to mean any state in which an instrument is kept when it is not in use.) Museums and other collections provide substantial evidence of the often astonishing extent to which instruments can become deformed through nothing other than the action of unsuitable climatic conditions. Much damage of this type can be prevented if measures are taken to maintain a proper storage environment.

The necessity for concern with storage conditions is greater than ever before. Modern, well-heated and well-illuminated living spaces give rise to risks that are likely to increase as time goes on, so that even more damage may be caused in the future than has unnecessarily been suffered in the past. A proper storage environment for musical instruments has two important properties: it subjects the instruments neither to undue mechanical stress nor to extreme climatic conditions. The purely mechanical side of the problem is reasonably straightforward. There are better and worse resting positions for every instrument; there are also, of course, many other important factors to be considered, but these are not the subject of this article.

Defining proper climatic conditions is considerably more difficult. For an instrument made of a single material, matters are relatively simple; but most musical instruments are made of more than one material, each of which may have quite different individual requirements. When several instruments of different types are to be stored together the problem can become very complex indeed. The best possible situation is no more than the compromise that will be as beneficial as possible to the largest amount of the material without being directly harmful to any of it. Museums are faced with this problem on a very broad basis and have found workable solutions which are also suitable for smaller-scale application.

Climate control means basically the control of light and air. Reduced to its essentials, the problem with light is one of controlling levels of visible and ultraviolet radiation and radiant heat. In a darkened storage area, for example a cupboard or closed instrument case, these factors are negligible. But where instruments are stored exposed, as in ordinary living quarters, illumination may require control. Light levels are expressed in terms of illuminance, measured in the unit 'lux'. Recommended safe museum illuminance levels range between 50 and 150 lux for different materials. The latter value is somewhat lower than that illuminating the indirectly lit surfaces in a room lit through its windows by a clear midday sky with no direct sunlight entering the room; 50 lux corresponds roughly to conditions in a room lit with diffused incandescent light after sunset. Thus if the direct light of the sun and uncovered incandescent bulbs is avoided, light levels may be satisfactory for most normal instruments. When dealing with instruments of greater value, however, illuminance should be measured and controlled more exactly. Special lux meters are available, but any photographic incident light meter can be used to make such measurements. The illuminance required to expose properly 100ASA film at 1 second and f5.6 is 110 lux. Lux is doubled or halved for each stop above or below this setting.

The duration of exposure of an instrument to light affects the risk of damage, so although recommended values may be safely exceeded for short periods, it is inadvisable to maintain high levels of light for very long. The obvious remedy for unacceptably high illuminance is to reduce the strength of the light source, by shading with window blinds if the problem is caused by daylight, or by using fewer or weaker light bulbs if lighting is artificial. Potentially dangerous levels of ultraviolet radiation are present in daylight and the light produced by some fluorescent lamps. Direct daylight can be screened. The use of fluorescent tubes that are specified as having low ultraviolet emission reduces the risks with that type of lighting. If these precautions are taken and the 150 lux level is not exceeded, light will present no great danger. Depending on the value of the instruments concerned, these formal recommendations may be taken more or less seriously. With the exception of the consequences of exposure to direct sunlight or intense daylight, the actual damage that may be caused by light will often be so small as to go unnoticed.

It is, however, not wise to be so casual about the deleterious effects of unsuitable atmospheric conditions. Airborne pollutants are an increasingly serious problem, to which there is no simple solution. For present purposes little more can be suggested than to avoid storing instruments in rooms directly exposed to the automobile exhaust products with which urban air abounds. Industrial waste is a far greater cause for concern but must be dealt with at its source. Few museums have adequate air-filtering systems and it is extremely difficult to recommend simple ones for domestic use.

Atmospheric humidity presents serious problems to which there are, however, satisfactory solutions that can be implemented on several levels of complexity. It is here that difficulties are caused by the various requirements of different materials. All materials may be classified as hygroscopic (capable of absorbing and yielding water) or non-hygroscopic. The atmosphere itself is hygroscopic: air is a mixture of gases, including water vapour; the amount of water vapour that it can contain is dependent on the air's temperature and, to a much lesser extent, its (barometric) pressure. The mass of water vapour contained in a specified volume of air is called 'absolute humidity', which can be expressed in grams of water vapour per cubic metre of air. For any temperature there will be a maximum absolute humidity. The ratio of the absolute humidity to the maximum possible at a given temperature is called 'relative humidity', and is usually expressed as a percentage (%RH). 100%RH means that the air is saturated and will not be able to absorb water from other materials. (If the temperature of saturated air is lowered the excess water will be forced out of the air by condensation.) As relative humidity decreases, the ability of the air to absorb water from other sources increases.

Organic materials such as wood have a moisture content which is affected by the relative humidity of the surrounding air. If wood is exposed over a long period to a constant relative humidity its moisture content tends to achieve equilibrium with that of the air. If the relative humidity is then increased the wood will absorb moisture from the air, and if the relative humidity is decreased the air will absorb moisture from the wood. This moisture content has an extremely important consequence: it affects the physical dimensions of the wood. Stated simply, wood swells as moisture is gained and shrinks as it is lost.

Unless artificial methods are used for its stabilization relative humidity fluctuates constantly. As a result wood will constantly be absorbing or yielding water, and its dimensions will also fluctuate. Wood is normally capable of responding elastically to small stresses such as those caused by limited variations in relative humidity. If this elastic range is exceeded, especially for a long time, the wood may crack if it becomes too dry, or it may be deformed plastically—that is, the wood may 'creep' internally and assume a new permanent form. In a temperate climate the normal seasonal variations in outdoor relative humidity will not usually subject seasoned wood to stresses to which it cannot respond elastically. Indoor conditions parallel outdoor conditions except during the period of the year when artificial heating is used. During the winter it is therefore perfectly possible for indoor relative humidity to drop well below the level at which wood responds elastically, and cracking and shrinkage will result. If dry conditions are extreme and protracted (as they often are), plastic deformation is also likely, and it may not always be possible for the wood to return to the dimensions it had before the damage occurred, however high relative humidity levels subsequently become.

The effects of excessive dryness on wood are well known. Less so is a phenomenon called 'compression shrinkage'. If a piece of wood is wetted and mechanically constrained from swelling, it will, upon drying, have smaller dimensions than it had initially. If it is also constrained from this shrinkage it can crack. Thus excessively high humidity levels can have the same effect as those of the opposite extreme.

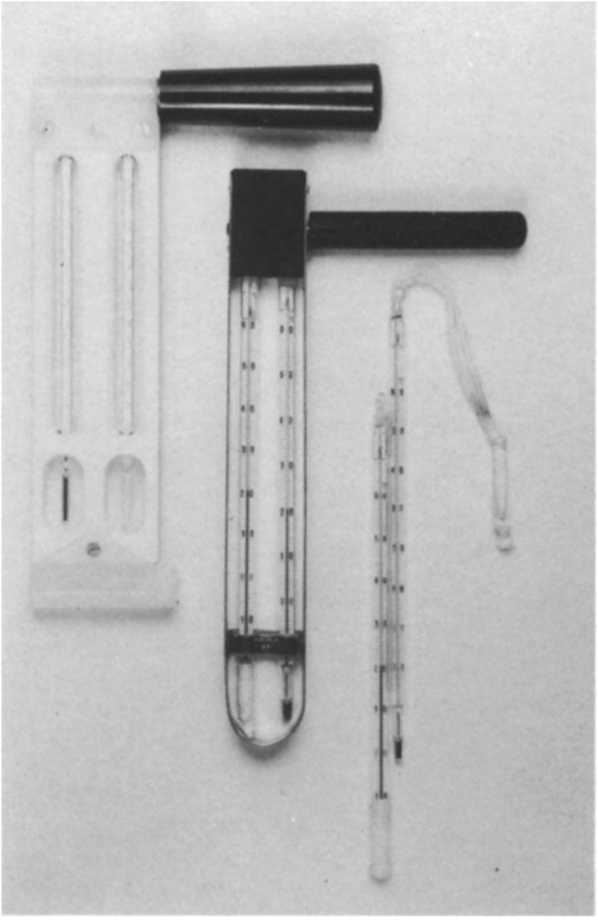
It should now be quite obvious that appropriate relative humidity is a very important feature of an environment suitable for musical instruments. The formulation of precise recommendations as to relative humidity levels, however, remains a problem. Ideally a musical instrument should retain its original physical dimensions. The dimensions of any non-hygroscopic materials (primarily metals) that it might contain are not affected by relative humidity, and so present no problem in this regard. Since the dimensions of organic materials (all hygroscopic—such as wood, leather, ivory, horn etc) are affected by relative humidity, the ideal level for a given instrument would appear to be the one with which its organic components were in equilibrium at the time of the instrument's manufacture. If, however, any part of the instrument has become plastically deformed in response to a relative humidity substantially different from the initial equilibrium value, to maintain those original atmospheric conditions may subject the instrument to unnecessary internal stress without restoring it to its initial dimensions. In fact, if an instrument has been repaired—had cracks filled and the like—while in equilibrium with the deviant relative humidity, adjusting the relative humidity to its 'proper' level may simply cause renewed cracking and dimensional distortion. A more realistic 'ideal' relative humidity for a given instrument is the level at which it feels most 'comfortable', that is, when its internal mechanical stress is minimized.

It is thus clear that it is very difficult to define ideal conditions for a single musical instrument, and even more difficult to do so for a number of them, all of which may have been in initial equilibrium with different relative humidities and may have been exposed subsequently to a wide range of relative humidities. To make matters worse, inorganic materials are not indifferent to relative humidity, even if it does not affect their dimensions. Metal corrosion can be both initiated and sustained by atmospheric moisture. Here it is easy to be dogmatic: the lower the relative humidity to which metals are exposed the better. Fortunately, unless corrosion is already widespread, metals of the type encountered in musical instruments can usually withstand the higher relative humidity that is beneficial to the organic materials.

Some guide-lines for the control of humidity can now be suggested, although it should be realized that they are based on very broad generalizations. Instruments made of seasoned, air-dried timber of north European origin (and before the 19th century all wood from the area would have been treated in that way) were in initial equilibrium with 60–65%RH. At levels in excess of 65%RH the growth of mould is encouraged, insect pests flourish, and conditions are unsafe for all metals. The safe upper limit for tolerable relative humidity can therefore be set at 65%. The safe lower limit, determined by the risks of mechanical damage to organic materials discussed above, will be between 40 and 45%. Median safe values lie in the range 50–55%, which can be accepted as the best possible compromise. This level is also not excessively high for artificially dried wood intended to withstand very low humidities. Should such material cause concern, it is an easy matter to segregate it from material kept in conditions of artificially raised relative humidity. This solution is also, of course, the logical one for all metal instruments. It should be noted, as well, that many 'ethnic' instruments can survive only in extreme climatic conditions; the proper treatment of such items is a subject in itself.

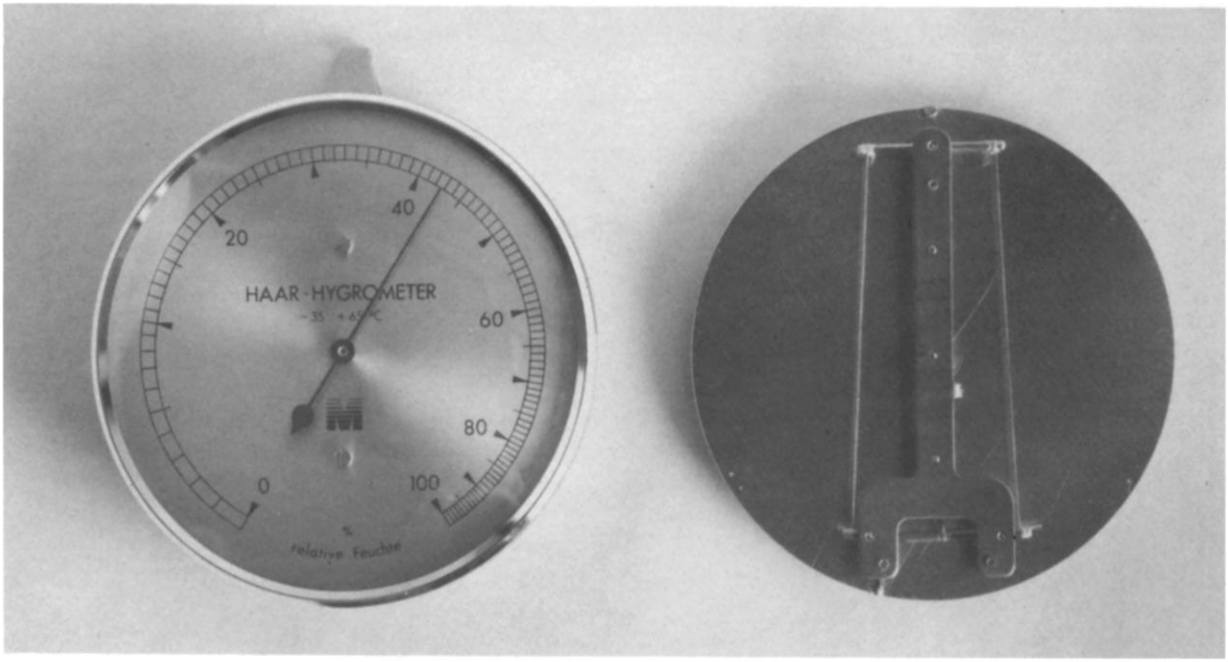
In all cases the goal of humidity control is the reduction of variation in relative humidity. Within reasonable limits, the absolute level at which relative humidity is stabilized is less important than the fact that a stable state is achieved. In locations where outdoor climatic conditions tend to be extreme, lower or higher values than those recommended may have to be adopted. Moreover, if the instruments are frequently removed from the controlled environment to uncontrolled surroundings, the former conditions should not differ too greatly from the latter.

The first step in controlling humidity is to measure relative humidity levels. There are several devices with which this can be done, the most common being the hair hygrometer. Here the hygroscopic action of



3 ***(right)*** **Sling psychrometers:** ***(top)*** **a 'professional' type with water reservoir, available from suppliers of meteorological or climate-control equipment;** ***(middle)*** **a simpler design, available from suppliers of thermometers or general scientific equipment;** ***(below)*** **a home-made type produced by gluing together two inexpensive thermometers with a piece of shoelace on the wet bulb. There are no inherent differences in the accuracy of any of these three types**

2 External and internal views of the simplest and least expensive type of hair hygrometer



human hair (it extends when moistened and contracts when dried) is used to move an indicator round a dial graduated in %RH (illus.2). A good hair hygrometer can be reasonably accurate when properly used and is very helpful, but proper usage includes regular calibration with a more accurate measuring device at intervals of about a fortnight; if this is not done, the hair hygrometer can show quite incorrect values and it should not, therefore, be relied upon unchecked. The sling psychrometer (illus.3) is the most common of the accurate humidity-measuring devices. It consists of two ordinary thermometers, the bulb of one of which is covered with a textile sleeve. This sleeve is saturated with water which evaporates as the psychrometer is swung through the air. The evaporation lowers the temperature of the wet bulb, which will stabilize at a value in equilibrium with the air's ability to absorb moisture from the sleeve. Since the air's ability to do this depends on its relative humidity, the wet- and dry-bulb temperatures can easily be used to determine that value (see Table 1).

After accurate measurements of relative humidity have been made, it will be possible to determine whether conditions are satisfactory as they are, or if humidification or dehumidification should be attempted. The latter is likely to be necessary only in summertime. Air-conditioning units, which are designed to lower indoor temperatures, also function as dehumidifiers. If excessive humidity is an acute problem (that is, if relative humidity is consistently over 70% for more than 12 hours per day over periods of weeks) the use of such apparatus should be considered. Other types of dehumidifiers exist, but most function on the same principle as the air-conditioner, which is the most accessible and convenient choice. The most common risk of moderate excess humidity—

Table 1 Relative humidity from wet and dry bulb temperatures

Dry bulb	Wet bulb depression (°C)																										
(°C)	0·2	0·4	0·6	0·8	1·0	1·2	1·4	1·6	1·8	2·0	2·5	3·0	3·5	4·0	4·5	5·0	6·0	7·0	8·0	9·0	10	11	12	13	14	15	16
0	96	93	89	86	82	79	75	72	69	65	57	49	41	33	25	17	2										
1	97	93	90	86	83	81	77	74	71	68	60	52	44	36	29	21	7										
2	97	93	90	87	84	80	77	74	71	68	62	54	47	40	32	25	11										
3	97	94	91	88	84	81	78	75	72	69	62	54	50	43	36	29	16	3									
4	97	94	91	88	85	82	79	76	73	70	63	56	49	42	39	33	20	7									
5	97	94	91	88	86	83	80	77	74	72	65	58	51	45	38	32	25	12									
6	97	94	92	89	86	83	81	78	75	73	66	60	53	47	41	35	23	16	5								
7	97	95	92	89	87	84	81	79	76	74	67	61	55	49	43	37	26	14	9								
8	97	95	92	90	87	85	82	80	77	75	69	63	57	51	45	40	29	18	7	3							
9	97	95	93	90	88	85	83	80	78	76	70	64	58	53	47	42	31	21	11	1							
10	98	95	93	90	88	86	83	81	79	77	71	65	60	54	49	44	34	24	14	5							
11	98	95	93	91	88	86	84	82	80	77	72	66	61	56	51	46	36	26	17	8							
12	98	95	93	91	89	87	84	82	80	78	73	68	63	57	53	48	38	29	20	11	3						
13	98	96	93	91	89	87	85	83	81	79	74	69	64	59	54	49	40	31	23	14	6						
14	98	96	94	92	90	87	85	83	81	79	74	70	65	60	56	51	42	33	25	17	9	2					
15	98	96	94	92	90	88	86	84	82	80	75	71	66	61	57	52	44	36	27	20	12	5					
16	98	96	94	92	90	88	86	84	82	81	76	71	67	62	58	54	46	37	30	22	15	8	1				
17	98	96	94	92	90	89	87	85	83	81	77	72	68	64	59	55	47	39	32	24	17	10	4				
18	98	96	94	92	91	89	87	85	83	82	77	73	69	65	60	56	49	41	34	27	20	13	7				
19	98	96	94	93	91	89	87	86	84	82	78	74	70	65	61	58	50	43	35	29	22	15	9	3			
20	98	96	95	93	91	89	88	86	84	83	78	74	70	66	62	59	51	44	37	30	24	18	12	6			
21	98	96	95	93	91	90	88	86	85	83	79	75	71	67	63	60	52	46	39	32	26	20	14	8	3		
22	98	97	95	93	92	90	88	87	85	83	79	76	72	68	64	61	54	47	40	34	28	22	16	11	5		
23	98	97	95	93	92	90	89	87	85	84	80	76	72	69	65	62	55	48	42	36	30	24	18	13	8	3	
24	98	97	95	94	92	90	89	87	86	84	80	77	73	69	66	62	56	49	43	37	31	26	20	15	10	5	
25	98	97	95	94	92	91	89	87	86	84	81	77	74	70	67	63	57	50	44	38	33	27	22	17	12	7	3
26	98	97	95	94	92	91	89	88	86	85	81	78	74	71	67	64	58	51	46	40	34	29	24	19	14	9	5
27	98	97	95	94	92	91	89	88	87	85	82	78	75	71	68	65	59	52	47	41	36	30	25	21	16	11	7
28	98	97	95	94	93	91	90	88	87	85	82	79	75	72	69	65	59	53	48	42	37	32	27	22	18	13	9
29	99	97	96	94	93	91	90	88	87	86	82	79	76	72	69	66	60	54	49	43	38	33	28	24	19	15	11
30	99	97	96	94	93	91	90	89	87	86	83	79	76	73	70	67	61	55	50	44	39	34	30	25	21	17	13
31	99	97	96	94	93	92	90	89	88	86	83	80	77	73	70	67	62	56	51	45	41	36	31	27	22	18	14
32	99	97	96	94	93	92	90	89	88	86	83	80	77	74	71	68	62	57	52	46	42	37	32	28	24	20	16
33	99	97	96	94	93	92	90	89	88	87	83	80	77	74	71	69	63	58	52	47	43	38	34	29	25	21	17
34	99	98	97	95	93	92	90	89	88	87	84	81	78	75	72	69	64	58	53	48	44	39	35	30	26	23	19
35	99	98	97	95	93	92	90	89	88	87	84	81	78	75	72	70	64	59	54	49	44	40	36	32	28	24	20
36	99	98	97	95	94	92	90	89	88	87	84	81	78	76	73	70	65	60	55	50	45	41	37	33	29	25	21
37	99	98	97	95	94	93	91	90	88	87	85	82	79	76	73	70	65	60	55	51	46	42	38	34	30	26	23
38	99	98	97	95	94	93	91	90	88	88	85	82	79	76	74	71	66	61	56	51	47	43	39	35	31	27	24
39	99	98	97	95	94	93	91	90	88	88	85	82	79	77	74	71	66	61	57	52	48	44	40	36	32	28	25

D. M. Unwin, *Microclimate Measurement for Ecologists* (Academic Press: London, 1980) the growth of mould—can be reduced by increasing air circulation in the problem area with an electric fan.

The need for humidification, largely a winter-time problem, is relatively easy to meet as it is far less difficult and costly to add water vapour to the air than it is to remove it. (Human beings may also benefit from winter-time humidification indoors. Especially at night, when the rate of swallowing decreases, mucous membranes may dry out and become more susceptible to infection than is usually the case.) There are three types of electrically operated humidifier generally available. The centrifugal (or atomizing) humidifier separates water into very fine droplets which are fanned out into the air and evaporate. A serious disadvantage of such devices (which makes it impossible to recommend them) is that they require the use of demineralized water; if tap water were used the minerals it contained would also be dispersed into the air and would eventually settle as a chalky deposit somewhere in the room. The evaporative humidifier is the most common type for use in small rooms. It contains an absorbent material which draws up water from a reservoir. A fan circulates the air in the room past this material, evaporating the water in the process. In larger devices (which also filter the air) a drum covered with a layer of sponge rotates through the water reservoir. All minerals remain in the humidifier, which will require regular cleaning if it is to retain its efficiency. Evaporative humidifiers cannot maintain relative humidity much higher than 70%, which provides a degree of safety if the device should ever run uncontrolled. The third type is the heated humidifier, which simply heats a pool of water until it evaporates. Having no mechanical parts this device has the obvious advantage of simplicity. A tea-kettle can do reasonable service as a heated humidifier, as will an immersion heater in a bowl of water, or a pot of water on a hot-plate.

In small rooms all three types use essentially identical amounts of energy to do their job. The heated humidifier uses substantial quantities of electricity but provides heated water vapour and can even assume some of the burden of heating the room. The centrifugal and evaporative types use less electrical energy to evaporate the water but cool the room in the process, thus creating a greater load on the room's heating system. A humidistat should be used to turn the humidifier on and off in response to room humidity. The centrifugal and evaporative humidifiers can be controlled with a humidistat to much finer tolerances than can the heated type. Bearing all this in mind, the choice of a humidifier is a matter of preference and initial cost (on this point the heated type wins easily) as long as the device selected has an adequate capacity.

In order to determine the humidification or dehumidification requirements of a room, absolute humidity data must be available (see Table 2). If a room of 60 cubic m is to be kept at 20°C and 50%RH the table shows that each cubic metre of air in the room must contain 8.7 grams of water vapour. If the most extreme unhumidified conditions in that room are a relative humidity of 30% at 20°C (that is, the air contains 5.2 grams of water vapour per cubic metre), the desired increase in relative humidity will require the addition of (8.7 − 5.2) x 60 = 210 grams of water to the air in the room. Since few rooms are airtight, this water vapour will need to be replenished more or less continuously. The air in a normal room with closed windows and doors will change about once an hour. If this is the case with the room of 60 cubic m, 210 grams of water vapour will be required per hour. One litre of water evaporates to produce one kilogram of water vapour. A humidifier capable of evaporating half a litre per hour will be necessary to achieve the required relative humidity—the extra capacity is needed to compensate for water vapour lost through condensation or absorption to furniture, walls, curtains etc. Water vapour may freeze near the exterior surface of a wall through which it escapes and cause damage. If any signs of this are visible room humidity should be reduced. It may help to insulate around the windows and doors of rooms to be humidified (or dehumidified).

In the preceding calculation the conditions to be achieved are a matter of choice. The lowest level of relative humidity must be determined either by direct measurement on a very cold day, or from information obtained from a local meteorological station. Absolute humidity is little affected by temperature, so extreme absolute humidities outdoors will be very close to those encountered in the heated indoors. Upon reflection it will become obvious that indoor winter relative humidity depends far less on outdoor relative humidity, than it does on the indoor–outdoor temperature difference.

It is also possible to determine water requirements, including compensation for losses due to absorption, condensation and ventilation, by experiment. Since the difference between outdoor and indoor tem-

Table 2 Absolute humidity (in grams per cubic metre) from relative humidity and temperature

Temp.	Relative humidity (%)																			
(°C)	100	96	92	88	84	80	76	72	68	64	60	56	52	48	44	40	36	32	28	24	20
0	4·8	4·7	4·5	4·3	4·1	3·9	3·7	3·5	3·3	3·1	2·9	2·7	2·5	2·3	2·1	1·9	1·7	1·6	1·4	1·2	1·0
1	5·2	5·0	4·8	4·6	4·4	4·2	3·9	3·7	3·5	3·3	3·1	2·9	2·7	2·5	2·3	2·1	1·9	1·7	1·5	1·2	1·0
2	5·6	5·3	5·1	4·9	4·7	4·4	4·2	4·0	3·8	3·6	3·3	3·1	2·9	2·7	2·4	2·2	2·0	1·8	1·6	1·3	1·1
3	6·0	5·7	5·5	5·2	5·0	4·8	4·5	4·3	4·0	3·8	3·6	3·3	3·1	2·9	2·6	2·4	2·1	1·9	1·7	1·4	1·2
4	6·4	6·1	5·9	5·6	5·3	5·1	4·8	4·6	4·3	4·1	3·8	3·6	3·3	3·1	2·8	2·5	2·3	2·0	1·8	1·5	1·3
5	6·8	6·5	6·3	6·0	5·7	5·4	5·2	4·9	4·6	4·4	4·1	3·8	3·5	3·3	3·0	2·7	2·4	2·2	1·9	1·6	1·4
6	7·3	7·0	6·7	6·4	6·1	5·8	5·5	5·2	4·9	4·6	4·4	4·1	3·8	3·5	3·2	2·9	2·6	2·3	2·0	1·7	1·5
7	7·7	7·4	7·1	6·8	6·5	6·2	5·9	5·6	5·3	5·0	4·6	4·3	4·0	3·7	3·4	3·1	2·8	2·5	2·2	1·9	1·5
8	8·3	7·9	7·6	7·3	6·9	6·6	6·3	6·0	5·6	5·3	5·0	4·6	4·3	4·0	3·6	3·3	3·0	2·6	2·3	2·0	1·7
9	8·8	8·5	8·1	7·8	7·4	7·1	6·7	6·3	6·0	5·6	5·3	4·9	4·6	4·2	3·9	3·5	3·2	2·8	2·5	2·1	1·8
10	9·4	9·0	8·6	8·3	7·9	7·5	7·1	6·8	6·4	6·0	5·6	5·3	4·9	4·5	4·1	3·8	3·4	3·0	2·6	2·3	1·9
11	10·0	9·6	9·2	8·8	8·4	8·0	7·6	7·2	6·8	6·4	6·0	5·6	5·2	4·8	4·4	4·0	3·6	3·2	2·8	2·4	2·0
12	10·7	10·2	9·8	9·4	9·0	8·5	8·1	7·7	7·2	6·8	6·4	6·0	5·5	5·1	4·7	4·3	3·8	3·4	3·0	2·6	2·1
13	11·3	10·9	10·4	10·0	9·5	9·1	8·6	8·2	7·7	7·3	6·8	6·4	5·9	5·4	5·0	4·5	4·1	3·6	3·2	2·7	2·3
14	12·1	11·6	11·1	10·6	10·1	9·7	9·2	8·7	8·2	7·7	7·2	6·8	6·3	5·8	5·3	4·8	4·3	3·9	3·4	2·9	2·4
15	12·8	12·3	11·8	11·3	10·8	10·3	9·7	9·2	8·7	8·2	7·7	7·2	6·7	6·2	5·6	5·1	4·6	4·1	3·6	3·1	2·6
16	13·6	13·1	12·5	12·0	11·4	10·9	10·4	9·8	9·3	8·7	8·2	7·6	7·1	6·5	6·0	5·4	4·9	4·4	3·8	3·3	2·7
17	14·5	13·9	13·3	12·7	12·2	11·6	11·0	10·4	9·8	9·3	8·7	8·1	7·5	6·9	6·4	5·8	5·2	4·6	4·1	3·5	2·9
18	15·4	14·7	14·1	13·5	12·9	12·3	11·7	11·1	10·4	9·8	9·2	8·6	8·0	7·4	6·8	6·1	5·5	4·9	4·3	3·7	3·1
19	16·3	15·6	15·0	14·3	13·7	13·0	12·4	11·7	11·1	10·4	9·8	9·1	8·5	7·8	7·2	6·5	5·9	5·2	4·6	3·9	3·3
20	17·3	16·6	15·9	15·2	14·5	13·8	13·1	12·4	11·8	11·1	10·4	9·7	9·0	8·3	7·6	6·9	6·2	5·5	4·8	4·1	3·5
21	18·3	17·6	16·9	16·1	15·4	14·7	13·9	13·2	12·5	11·7	11·0	10·3	9·5	8·8	8·1	7·3	6·6	5·9	5·1	4·4	3·7
22	19·4	18·6	17·9	17·1	16·3	15·5	14·8	14·0	13·2	12·4	11·6	10·9	10·1	9·3	8·5	7·8	7·0	6·2	5·4	4·7	3·9
23	20·6	19·7	18·9	18·1	17·3	16·5	15·6	14·8	14·0	13·2	12·3	11·5	10·7	9·9	9·0	8·2	7·4	6·6	5·8	4·9	4·1
24	21·8	20·9	20·0	19·2	18·3	17·4	16·5	15·7	14·8	13·9	13·1	12·2	11·3	10·4	9·6	8·7	7·8	7·0	6·1	5·2	4·4
25	23·0	22·1	21·2	20·3	19·3	18·4	17·5	16·6	15·7	14·7	13·8	12·9	12·0	11·1	10·1	9·2	8·3	7·4	6·4	5·5	4·6
26	24·4	23·4	22·4	21·4	20·5	19·5	18·5	17·5	16·6	15·6	14·6	13·6	12·7	11·7	10·7	9·7	8·8	7·8	6·8	5·8	4·9
27	25·8	24·7	23·7	22·7	21·6	20·6	19·6	18·5	17·5	16·5	15·5	14·4	13·4	12·4	11·3	10·3	9·3	8·2	7·2	6·2	5·2
28	27·2	26·1	25·0	23·9	22·9	21·8	20·7	19·6	18·5	17·4	16·3	15·2	14·2	13·1	12·0	10·9	9·8	8·7	7·6	6·5	5·4
29	28·7	27·6	26·4	25·3	24·1	23·0	21·8	20·7	19·5	18·4	17·2	16·1	14·9	13·8	12·6	11·5	10·3	9·2	8·0	6·9	5·7
30	30·3	29·1	27·9	26·7	25·5	24·3	23·1	21·8	20·6	19·4	18·2	17·0	15·8	14·6	13·4	12·1	10·9	9·7	8·5	7·3	6·1
31	32·0	30·7	29·5	28·2	26·9	25·6	24·3	23·1	21·8	20·5	19·2	17·9	16·7	15·4	14·1	12·8	11·5	10·2	9·0	7·7	6·4
32	33·8	32·4	31·1	29·7	28·4	27·0	25·7	24·3	23·0	21·6	20·3	18·9	17·6	16·2	14·9	13·5	12·2	10·8	9·5	8·1	6·8
33	35·6	34·2	32·8	31·4	29·9	28·5	27·1	25·7	24·2	22·8	21·4	20·0	18·5	17·1	15·7	14·3	12·8	11·4	10·0	8·6	7·1
34	37·6	36·0	34·5	33·0	31·5	30·0	28·5	27·0	25·5	24·0	22·5	21·0	19·5	18·0	16·5	15·0	13·5	12·0	10·5	9·0	7·5
35	39·6	38·0	36·4	34·8	33·2	31·7	30·1	28·5	26·9	25·3	23·7	22·2	20·6	19·0	17·4	15·8	14·2	12·7	11·1	9·5	7·9
36	41·7	40·0	38·3	36·7	35·0	33·3	31·7	30·0	28·3	26·7	25·0	23·3	21·7	20·0	18·3	16·7	15·0	13·3	11·7	10·0	8·3
37	43·9	42·1	40·4	38·6	36·9	35·1	33·3	31·6	29·8	28·1	26·3	24·6	22·8	21·1	19·3	17·5	15·8	14·0	12·3	10·5	8·8
38	46·2	44·3	42·5	40·6	38·8	36·9	35·1	33·2	31·4	29·5	27·7	25·9	24·0	22·2	20·3	18·5	16·6	14·8	12·9	11·1	9·2
39	48·6	46·6	44·7	42·7	40·8	38·9	36·9	35·0	33·0	31·1	29·1	27·2	25·3	23·3	21·4	19·4	17·5	15·5	13·6	11·7	9·7

D. M. Unwin, *Microclimate Measurement for Ecologists* (Academic Press: London, 1980)

peratures affects the last two of these factors, tests should be made during extremely cold weather. Using any available humidifier—a tea-kettle will do admirably—the humidity of the room should be raised until desired conditions are attained. (If this is not possible a more powerful humidifier will be needed.) This level should then be maintained for several hours, careful note being taken of the amount of water evaporated by the humidifier. The water consumption per hour is easily calculated and the minimum capacity of a more permanent installation may thereby be determined.

A method of protecting the environment of exhibited objects from the seasonal variations in relative humidity is now being tested in museums: very large quantities of silica gel (an inert hygroscopic material) are added to the display case; during the summer the silica gel absorbs enough moisture from the atmosphere to be able to hold the relative humidity inside the case at acceptable levels throughout the winter. This reduces the range of annual variation in relative humidity to acceptable proportions and eliminates the need for auxiliary humidification. Fitted musical instrument cases can also be provided with silica gel reservoirs which will protect the instrument during short periods away from the acclimatized storage area. The instrument case is supplied with a quilt filled with as much silica gel as possible without its coming into direct contact with the instrument or posing any other mechanical threat to it. When in a suitably humidified area, the case is kept open so that the silica gel can quickly achieve equilibrium with the satisfactory climatic conditions. When removed to less hospitable surroundings the closed case will provide a good deal of climatic protection to its contents. Proprietary devices consisting of a roll of moisture-absorbent material in a rubber tube are designed to do the same thing, although they may not give either predictable or adequate results.

Throughout this discussion repeated mention has been made of temperature as it relates to humidity, but nothing has been said about the effect of heat itself on musical instruments. Surprisingly, heat is a rather unimportant factor, as instruments survive quite happily within the temperature range of the normal human environment. Sudden extreme changes can be very dangerous, but as long as they are avoided temperature need be considered only as it affects humidity.

This article may raise more questions than it answers. The complexity of the subject and the necessity to compromise in making recommendations of this nature unfortunately prevent universal guidelines from being formulated. Circumstances and individual judgement are the ultimate arbiters. It is hoped, nonetheless, that the above material and the notes that follow will be useful to readers in dealing with what is one of the most important aspects of the care of musical instruments.

Further information

The field of conservation has an extensive technical literature, most of which is probably too specialized to be of interest to the readers of this article. However, invaluable additional information is to be found in G. Thomson, *The Museum Environment* (London, 1978). Also, the Canadian Conservation Institute (1030 Innes Road, Ottawa, Ontario, K1A 0M8) publishes a series of technical bulletins several of which are quite useful, especially R. L. Barclay, *Care of Musical Instruments in Canadian Collections*, CCI Technical Bulletin no.4 (Ottawa, 1978). Many cities have at least one museum which has much of the relevant literature in its library. Museums that do not have this material should be able to refer to those that do.

As far as possible no recommendations have been made in this article which require the acquisition of exotic apparatus. The classified section of any larger telephone directory is likely to list all necessary sources of supply. Any photographic shop will sell light meters, and suppliers of electronic and climate-control equipment sell lux meters. These need not be expensive (and, indeed, may often not be necessary at all) but it is important to acquire a meter which is sufficiently sensitive at the low levels which are of concern. (If a photo salesman has never heard of 'lux', ask to leaf through the instruction booklet for the meter which you are considering. There will be a table there which converts the light meter's own scale values to lux.) Humidifiers are not hard to locate, either (check suppliers of air-conditioning equipment, home nursing equipment, hardware etc). Hair hygrometers are to be found together with things like barometers, cheap optical equipment etc. There are countless totally worthless hygrometers on the market, but even a modest *hair* hygrometer will do. (If you cannot easily see the hair inside do not accept it as a hair hygrometer.) Quality hair hygrometers are available from suppliers of climate-control, meteorological and general scientific equipment. Sling psychrometers are also available from these sources, as well as from thermometer specialists. In cases of difficulty the conservation department of any museum should be able to refer to local sources of supply.

Hygrometers and psychrometers are often provided with insufficient instructions for their correct use. It is important that a psychrometer be swung rapidly until its wet-bulb temperature stabilizes at a minimum value (2–3 turns per second for at least 2 minutes). It should be held at arm's length to reduce the influence of the operator's body temperature and water-vapour production. Several measurements must be made in different parts of a room if the relative humidity of the entire room is to be determined.

Hair hygrometers tend to become insensitive and inaccurate with time and must be regenerated several times a year. The same procedure should be followed before a new hygrometer is first used. The hygrometer should be wrapped up in a wet towel or left near a steaming bathroom shower until it responds maximally (it should read 95%, not 100%, when saturated). After several days at normal conditions it will stabilize and can be calibrated by reference to the psychrometer.