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Control of the Environment for Good or Ill? Monitoring

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The purpose of this article is not to emphasize yet again the importance of controlling humidity and light in museums. That goes without question. It is about maintaining this control in actual exhibition room conditions.

But surely, one might say, once we have specified, for example, that Relative Humidity (RH) must be held between 50% and 60%, we can then leave it all to the engineers who run the installation?

It is necessary to keep certain considerations in mind. Firstly the human body is very sensitive to temperature change. Complaints will flood in if offices get too hot or too cold by a couple of degrees. The body, however, is not nearly so sensitive to a change in RH. Just the reverse applies to moisture-responsive exhibits, such as those made of wood, natural textiles, bone, ivory and skin. But no one notices unless humidity goes to extremes. Secondly it is easy to measure temperature accurately with reliable instruments. By contrast, up to the present, instruments for measuring RH have been either difficult to use or unreliable or both. Here are three examples.

The unreliability of RH-measuring instruments

1. The wet-and-dry-bulb hygrometer in its familiar form as sling hygrometer is a reliable instrument in trained hands. If, however, the two thermometers are not matched to within 0.2°C, if the wick is allowed to dry out or to get encrusted, if slinging is not continued for long enough, it ceases to be reliable to within 2% RH.
2. The eight-day recording thermohygrograph (Fig.1) is an instrument widely used throughout the world. But if it is not recalibrated about every other month, for example with a sling hygrometer, it can gradually drift out of true until its readings are in error by 20% or more. It will still indicate change but otherwise its readings have become useless. The same goes for dial hygrometers.
3. As it is useful to get an electrical signal from an instrument, there is now a wide variety of electronic hygrometers on the market. Many of them rely on a plastic film which, being moisture-absorbent, changes its electrical characteristics with RH. These sensors are very easily contaminated by air pollutants and upset by the condensation of moisture.

So we have a problem with instrumentation. In general we also have a problem with staff.

Staff supervision

Museum curators, highly expert in their own fields, are not on the whole familiar with air-conditioning installations. The engineers running these installations cannot be expected to be familiar with antiquities. The response of exhibits to the environment is a field of knowledge largely foreign to both curators and engineers. It is therefore not surprising that there sometimes results a communications gap detrimental to the wellbeing of the exhibits.

Fortunately this is now coming to be recognized. A member of either the curatorial or conservation staff is given the duties of liaison with the engineers on environmental conditions. Further, control of heat, humidity and light in the modern museum has become too complex a task for the old boiler-room hand. The upgraded museum engineer has to be able to take immediate corrective action for the safeguarding of the collection. He is coming to understand the damage that uncontrolled humidity and light can do.

Control and monitoring

The difference between control and monitoring should be made clear. When all is well, air-conditioning systems operate without human interference. That is to say, the various heaters and humidifiers are controlled directly by sensors, which basically sense whether more or less is required and send signals accordingly to valves and switches. But independently of all this, we, as the human beings involved, wish to know how well things are operating: we require to monitor the system. For this purpose we could go round with a sling hygrometer, and this would be a monitoring operation. But it would take a great deal of time in a large museum, and records made in this way have a habit of getting lost. Therefore another set of sensors is set up which send their signals direct to dials, printers or a data logger. In general control sensors are placed where they can best respond to the effects of their control (perhaps in a duct), whereas monitoring sensors are placed near the exhibits because the purpose of this operation is to monitor the conditions where the exhibits are (Fig.2).

But the problem of how to organize effective monitoring has still to be worked out. Without this, dangerous conditions will remain undetected.

As an example, the Northern Extension to the National Gallery, with ten new exhibition rooms on the main floor was opened in June 1975. It is fully air-conditioned. As is customary, control of RH as well as temperature is by temperature-sensing devices because of their inherent reliability. It is beyond the scope of this article to explain how RH can be controlled by a thermometer. This depends on providing cool saturated air that will fall to the correct RH when brought up to room temperature. The monitoring or checking of the system, as opposed to its control, involves RH sensors in the exhibition rooms. The dials in the control room which received signals from these monitoring sensors were provided with high and low contacts such that, if the RH ran outside the specification, alarms were sounded. After a great deal of work and trouble — and potential damage to the exhibits — it was recognized that the sensors could not be made reliable. The alarm contacts were pushed aside and clockwork thermohygrographs reappeared in the exhibition rooms.

Concurrently the Scientific Department was setting up routine measurements of colour on paintings [1]. The objectives of this exercise are (a) to record colour change and (b) to discover the causes of the changes. For the attainment of the latter objective we had, at the same time, to secure adequate and reliable records of environmental conditions, particularly of RH, illuminance and temperature. These had to be in a form from which averages, etc., could easily be obtained without costly manual effort. Thermohygrograph records are not good in this respect. A computer-readable record was obviously going to be necessary, and so a data logger was acquired in 1974 with the capability of collecting readings from any required sensors hourly, and punching them onto paper tape. We hoped that the move of the Scientific Department to the Northern Extension would give us an opportunity to use the sensors installed in that building for the first stage of our log, and we received close cooperation from the Department of Environment architects and engineers working on the construction.

We therefore wired in to a selection of the RH-monitoring sensors, which, as mentioned above, later proved to be unreliable, and also to photocells controlling the fluorescent lamps in the exhibition rooms. These also turned out to be bad choices.

The photocells were installed high on the exhibition walls so as not to interfere with picture-hanging. Their purpose was to regulate dimmers on the lamps. Although the light from these lamps was stronger at the level of the photocells than at eye-level, a calibration adjustment took care of this for control purposes. But for monitoring things were not so satisfactory, since the light distribution was much more even from daylight than from the lamps. A calibration on one source would be incorrect for the other.

We realized that improvements in the logging of both RH and light had to be made. We began a test programme. But it will now be worthwhile to describe some of the basics of this kind of logging.

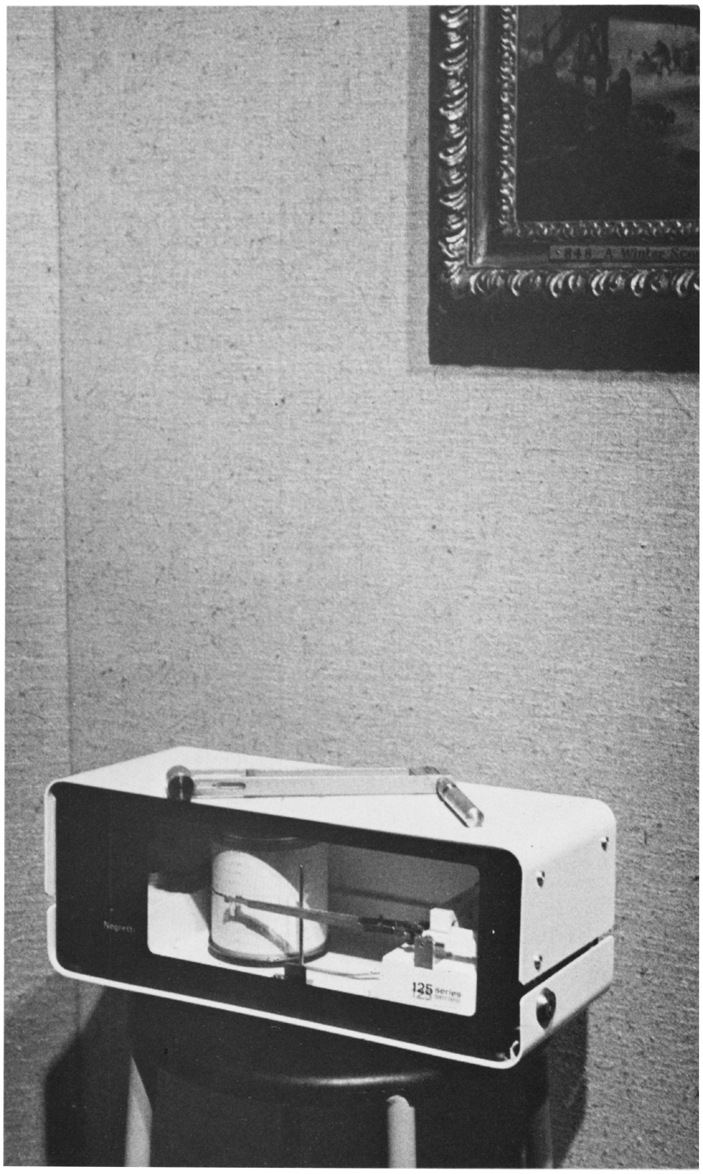


Figure 1 Conventional hygrometry in the exhibition room. A wet-and-dry bulb sling hygrometer lies on an 8-day recording thermohygrograph. The sling is used to recalibrate the thermohygrograph once every other month.

Data logging

It may now be apparent that there are three good reasons why we should collect, or log, data on the environment in museum exhibition or storage areas:

1. For control
2. For monitoring
3. For the long-term record

In the simplest situation none of these reasons need lead to the purchase of a logger, since: (1) simple thermostats and humidistats can be used to control room heaters and humidifiers (2) monitoring can be with sling hygrometer or with self-calibrating electronic hygrometer (Fig.3), and (3) long-term storage can consist of thermohygrograph charts which bear recalibration records.

Then why use a data logger? A data logger coupled with a microcomputer could very well be used for control as well as monitoring. But this we can regard as the final step, which had better be set aside for the moment while we consider (2) monitoring and (3) the long-term record.

Figure 2 An electronic impedance hygrometer (Rotronic), together with its controller, mounted at picture-level in an exhibition room.

Figure 3 Hand-held self-calibrating electronic hygrometer (Nova Sina Mik 5317). This type of instrument is very much easier to use than the sling hygrometer, and its accuracy can be checked at any time by placing a special cap over the sensor at the top of the instrument. This cap provides a standard RH (55% in this case) against which the instrument can be corrected.

Three advantages of the logger for monitoring and recording will occur to the engineer: it is (A) automatic, (B) remote and (C) centralized.

A. To employ a well qualified person such as a conservator to visit each room, hygrometer in hand, to change the paper on each thermohygrograph is wasteful of valuable skill. To employ an unskilled person is not only expensive but possibly dangerous to the collection.

B. Instead of a thermohygrograph on a table in the corner of the exhibition room (Fig.1) the data logger is not placed in the room at all, but at some remote location. All that is left in the room is a small sensor unobtrusively mounted on the wall (Fig.2).

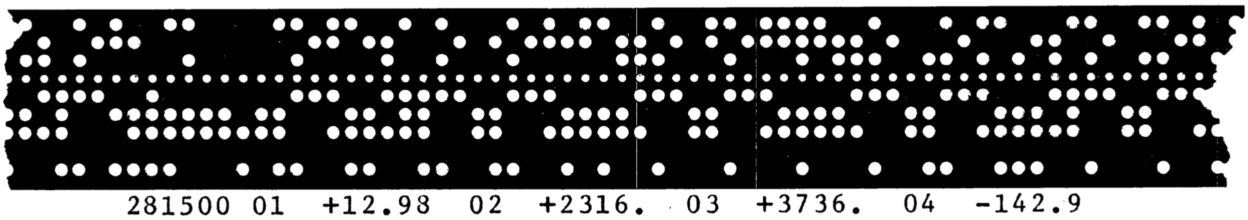
C. Cables from all over the museum can be brought to a data logger at some convenient central point.

Logger systems

The simplest kind of logger is an instrument connected by cables to a set of sensors all of the same kind, say thermometers. Each cable with its connecting terminals, each line of communication, is called a channel. One channel leads to one sensor. Since all the sensors in this case are not only thermometers but the same kind of thermometer, the logger need consist of little more than a meter dial or digital panel indicating temperature directly, and a multi-position switch. This kind of logging would be centralized though non-automatic.

The next stage is to provide the logger with a clock, a printer and a means of selecting the time interval between successive readings. Each set of readings will now consist of the date and time followed by channel number and temperature successively through all or selected channels. For the printer a choice must be made between man and machine. It can print figures on a roll of paper which can be read by a human operator or it can print computer-readable code either by punching holes in paper tape (Fig.4) or by imprinting an erasible pattern on magnetic tape or disc. Magnetic media have advantages over paper tape in re-usability and capacity. For example one week's hourly record for twenty channels on paper tape amounts to a reel about 12 cm. in diameter (Fig.5), whereas a multi-track magnetic tape recorder can compress a few hundred channels into a small cartridge (Fig.6).

But a logger must be more versatile than a collector of readings from just one type of instrument. In the National Gallery, for example, we log temperature, relative humidity and illuminance. This variety brings its crop of difficulties which, however, a good logger is designed to overcome. The two loggers now in the National Gallery exemplify two different approaches. Data logger A is a Christie Mycalex instrument bought by the Scientific Department in 1974 [2]. Data logger B is of more recent design: a Fluke instrument bought by the Department of the Environment (DoE) in 1980 (Fig.6).



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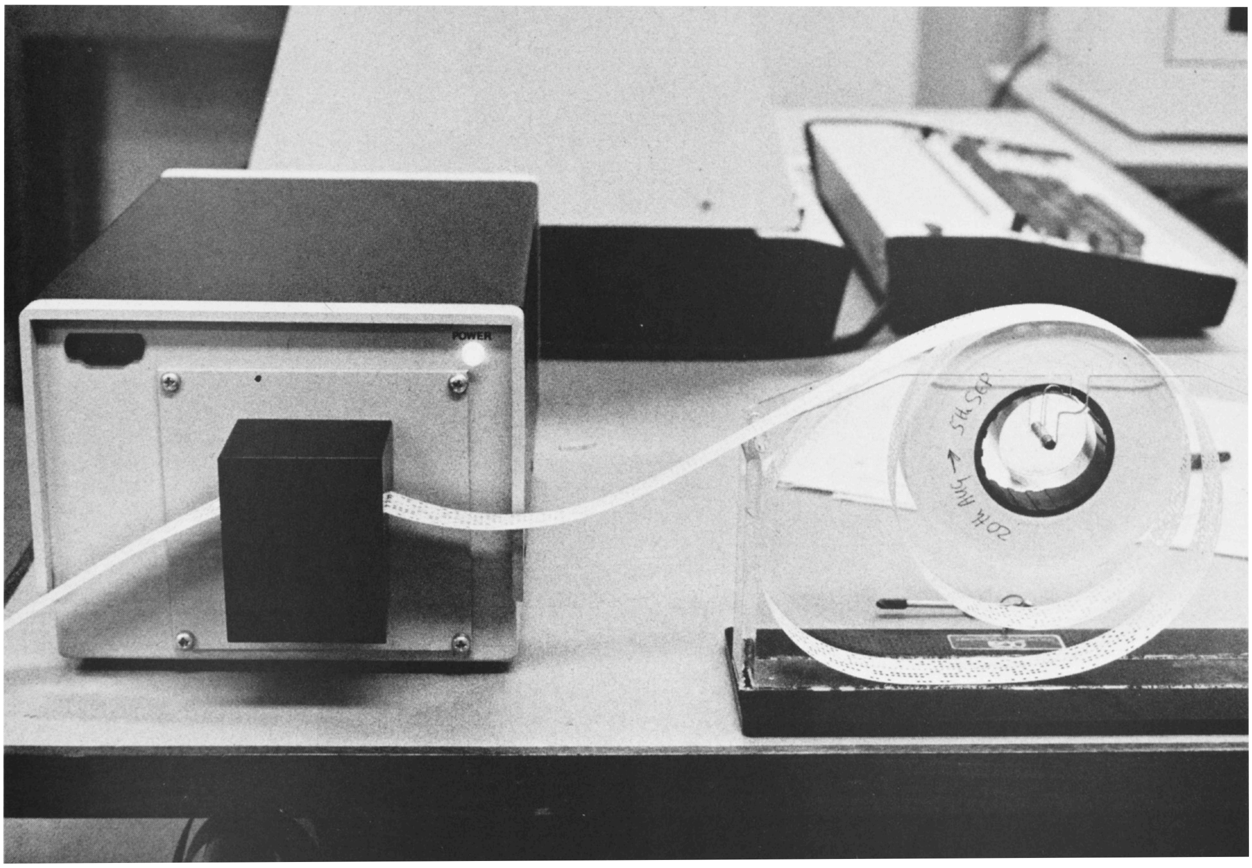

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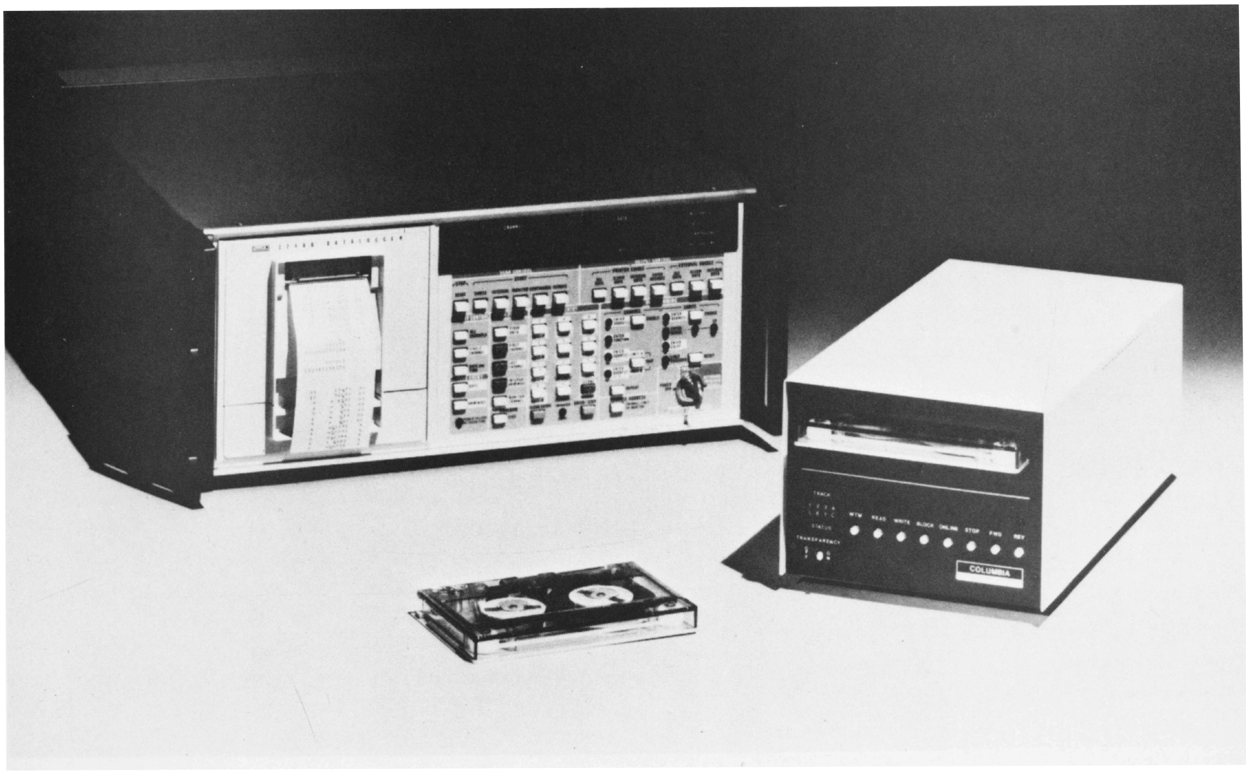

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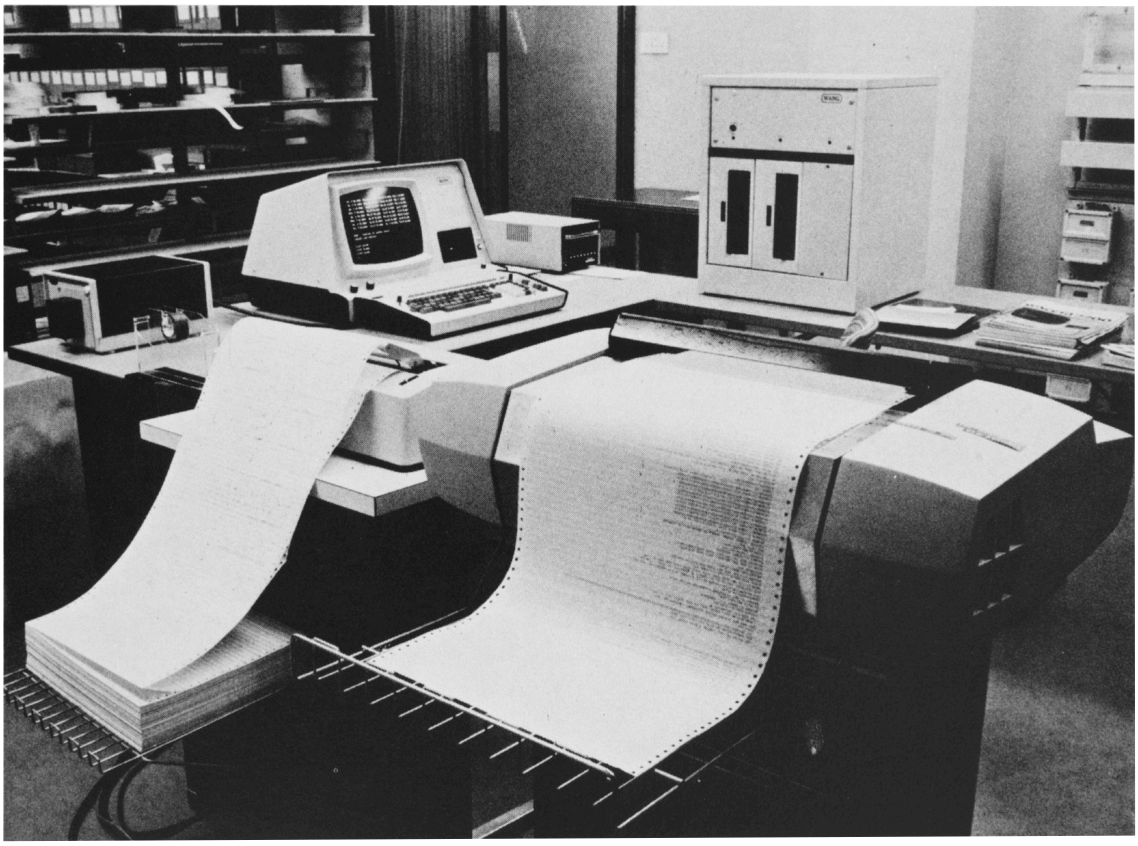


Data logger A

Why not simply record the voltages transmitted by the various sensors at fixed intervals of time? These voltages can later be converted by the computer into temperature, RH etc. The disadvantage is that we can no longer read any sensor on the logger in 'real time' without doing a simple conversion. For example the logger may tell us that the RH sensor on channel fifteen stands at 107 millivolts at this moment. To find out what the RH is now in the room corresponding to channel fifteen we must perform a simple conversion of the following kind:

RH = A + (millivolts × B)

where A and B are constants which must be known for each sensor. This operation is later performed automatically by the computer. It has the advantage that we can change the calibration by keying new figures into the computer rather than by operating on each sensor with a screw-driver.

So logger A collects the voltages on all its channels hourly, whatever kind of sensor they are connected to, and punches them onto paper tape. Once a week the tape is taken to the computer in the next room (Fig.7).

The job of the computer is as follows:

1. To read and store all the dates, times and voltages taken from the punched paper tape.
2. To convert voltages with the help of stored calibration constants to temperatures, RH, illuminance, etc. in accordance with pre-set instructions: at the same time to pack the data into a form suitable for economic storage.
3. To print tables and graphs as required.
4. To store the packed data on a suitable long-term storage medium.
5. To perform averaging calculations on the stored data as required.

Steps 1 to 4 could be made completly automatic, but in practice the operator is given the option of intervening at the end of each step before confirming the next.

The computer itself consists of a Central Processing Unit (CPU), the 'brain' which receives data and instructions on what to do with them. To carry out

Figure 7 The Scientific Department's Wang 2200 general computing system. In the foreground is a fast matrix printer and, next to it on the left, an IBM golf-ball printer/plotter. The screen and keyboard occupy the middle of the centre table, with at left the paper-tape reader, and at right the Columbia cartridge recorder. On the right, a dual floppy-disc drive unit (see also Fig. 9).

Figure 4 Standard 8-bit punched tape (ASCII code). In reading, ignore the lowest line of holes, which are 'parity bits' for an internal check. For example, the last typed digit on the right, 9, is punched as 00111001, reading upwards with 1 for a hole, 0 for no hole. This is divided into two sets of 4 bits, the first (0011) reading 3 in binary which is the code for numerals, the second (1001) reading 9. The transciption typed below the tape can be understood as follows: *Date:* 28. *Hour:* 1500. *Channel 01:* +12.98 millivolts. *Channel 02:* +2316 millivolts, and so on. Two end-of-reading characters occur between each set of figures.

Figure 5 Reader for punched paper tape. Characters are read at up to 300 per second, depending on the processing required during reading.

Figure 6 On the left, data logger B (Fluke 2240B). On the right, a magnetic tape cartridge recorder (Columbia 300D), with a cartridge in the foreground (size 10 × 15 cm.).

the instructions listed above, certain peripherals are also required (Fig.7):

A paper-tape reader

A printer and plotter (combined or separate)

A disc store for long-term storage.

In step 1, one day's set of data on twenty channels by the hour is read from the paper tape into an array in the CPU. An array is a device for storing data in an orderly arrangement which appears to the operator to be in rows and columns. Each day's data set is transferred after collection onto disc storage and the operation is repeated for the whole week. The data are now quickly accessible for further processing and the paper tape can be discarded, though it is normally kept for a week in case errors have to be traced back.

Before any computation takes place in step 2, the calibration constants which were used in the previous week are presented to the operator for change if necessary (Fig.8). Using these constants the voltages collected in step 1 are then converted to temperature, RH and illuminance. For compactness only 8 bits are allotted per reading. Any number up to 256 can be recorded in 8 bits [3]. To keep within this range, RH is stored unchanged, temperature is multiplied by 2 to give half degrees, and illuminance is divided by 5 so that it is recorded to the nearest 5 lux.

Step 3 involves a fast matrix printer for the written record and a much slower printer-plotter for graphs of each channel (Fig.7).

For step 4, long-term storage, the disc is again the medium. It is perhaps not quite as permanent as required, though a copy is taken. However it is compact: one 8-inch flexible disc will take a year's record of twenty channels by the hour (Fig.9).

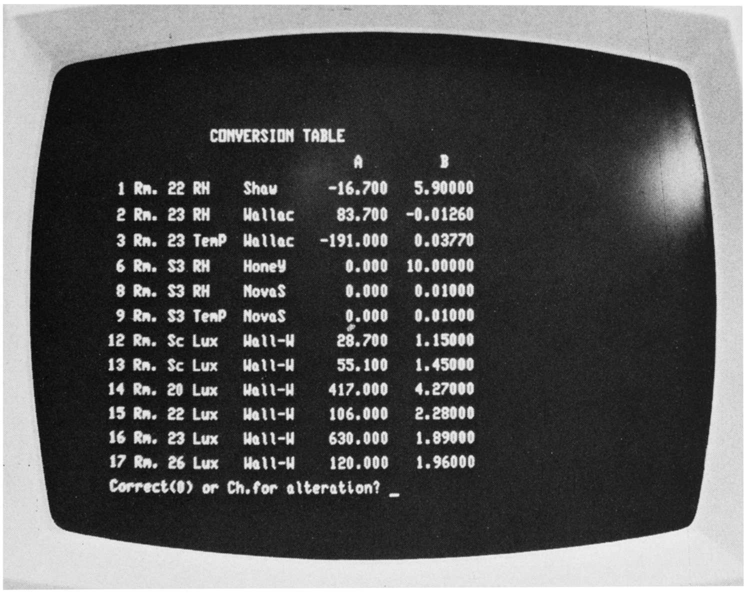
Programs may be written as required in step 5. We have a program for estimating annual exposure to light (Fig.10) and one for drawing histograms of RH values (Fig.11). However to get the best out of these programs one needs a long run of reliable data. There are a number of breaks in our record so far, mostly due to sensor failure.

Data logger B

Logger B (Fig.6) approaches things in a rather different manner. It was installed by the DoE with our advice, firstly to centralize their monitoring of temperature and RH in a large part of the Gallery (the West Wing and the Northern Extension), and secondly to provide the data for our long-term store.

The sensors are also rather different in design (Figs.2 and 12). They are mounted in pairs, one for temperature and one for RH. A controller with each sensor pair is connected to the mains, energizes the sensors, linearizes their outputs and converts them into figures which can be read directly. The purpose of linearization is to ensure that a graph of the linearized voltage, say, RH is a straight line. This voltage can then be biassed to read 0 at 0% RH and multiplied by a constant so that, for example, a sensor at 55.4% RH sends 55.4 millivolts to the logger.

At the logger various arrangements can be made. The engineer can key in the channel number



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MLXH (79/80)

Average Illuminance & Est.Annual Exposure

Week beginning	Hours	K.Lux hrs	Lux.1100-1700
07 Sep 79.	68	5.2	175
10 Sep 79.	142	13.4	184
17 Sep 79.	166	13.1	164
24 Sep 79.	168	14.5	172
01 Oct 79.	168	15.1	161
08 Oct 79.	168	13.6	150
22 Oct 79.	168	11.8	129
29 Oct/Nov 79.	168	10.7	123
05 Nov 79.	168	11.6	137
12 Nov 79.	182	18	183
19 Nov 79.	147	14.4	172
26 Nov/Dec 79.	142	12	164
10 Dec 79.	142	11.5	166
17 Dec 79.	179	12.9	144
TOTAL	2176	177.7	

Est.annual exposure on this basis = .72 Mlxh

Average Illum. 1100 through 1700hrs = 158 Lux.

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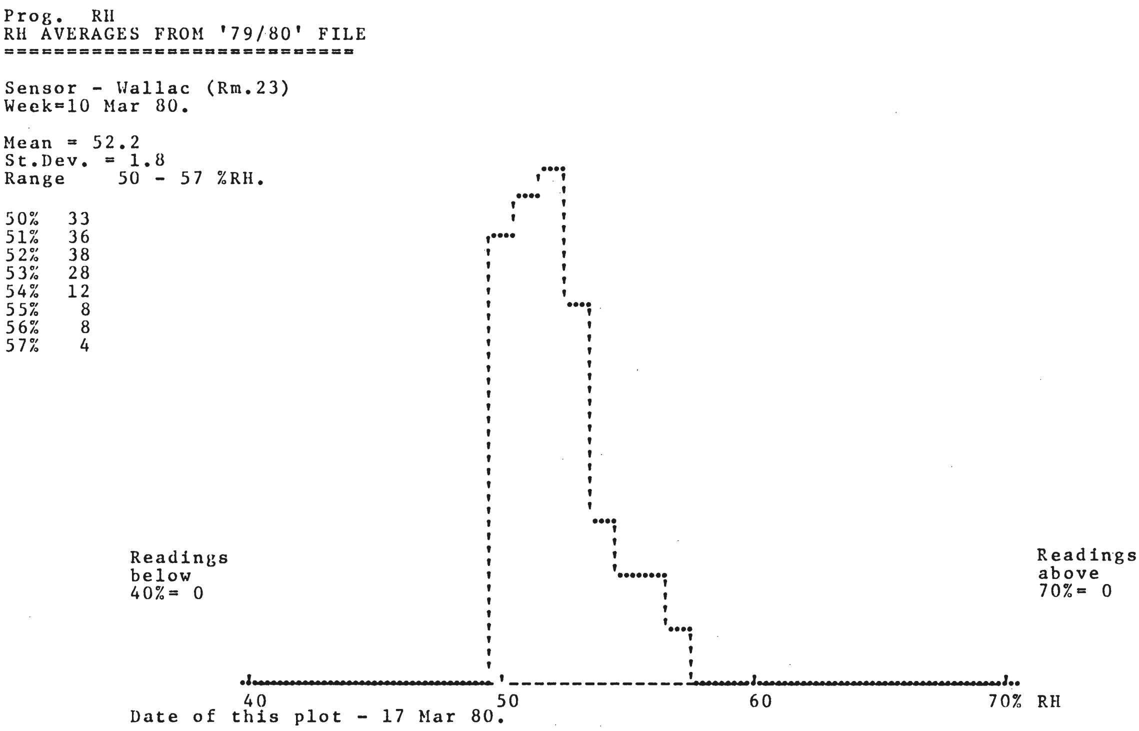

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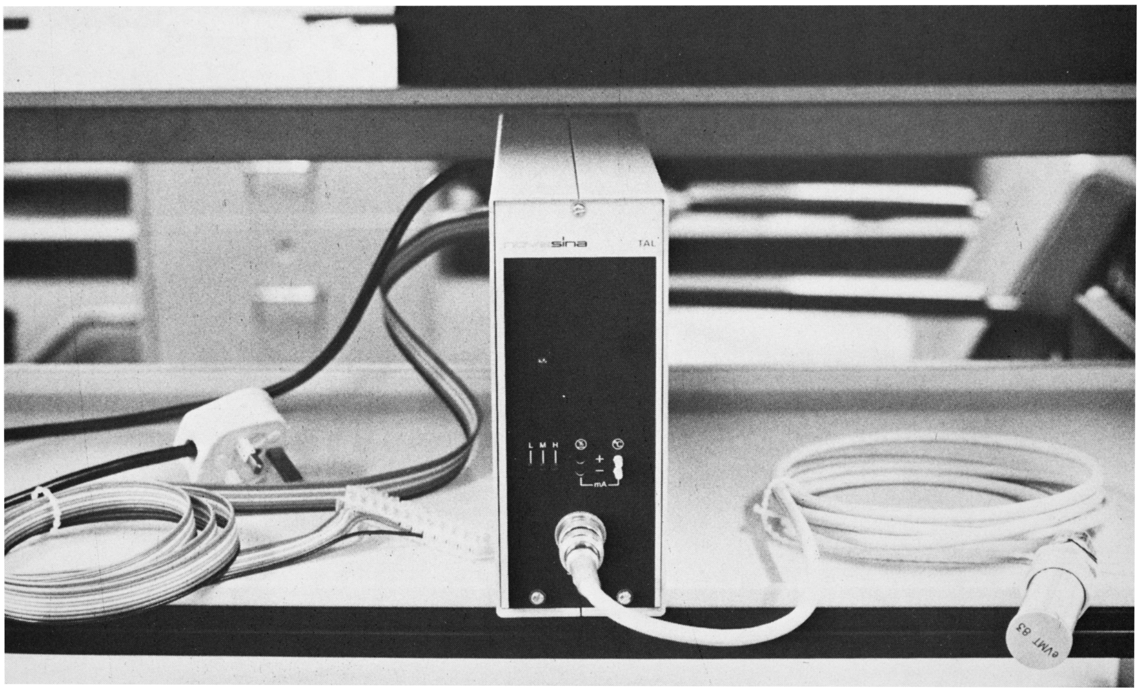

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Figure 8 Calibration constants for the sensors attached to data logger A, presented on the screen for correction before storage.

Figure 9 One of the 8-inch magnetic discs, known because of their flexibility as 'floppy discs', being inserted into the disc drive unit. The disc is contained permanently in its envelope and has a capacity, depending on packing density, of about 250,000 characters (¼ megabyte).

Figure 10 A print-out of annual exposure to light. After the week entry, the columns give: hours in the week's record; kilolux-hours exposure for that period; average illuminance in lux between 11.00 and 17.00 hrs (or any other chosen period). An annual exposure estimated on an average of 150 lux during ten opening hours and 10 lux during the rest of the day should be about 0.51 Mlxh (million lux-hours). The value estimated here is thus about 50% too high.

Figure 11 A computer print-out in the form of a histogram for the RH values in Room 23 for the week beginning 12 February 1980. The numerical values for the histogram are printed on the left.

Figure 12 Temperature/RH sensor (Nova Sina series 83). The sensor head is on the right and the linear converter or controller at centre. Sockets on the front of the converter allow temperature and RH outputs to be read with a meter for calibration. This is by means of three standard humidity caps (for 33.4, 54.9 and 75.5% RH at 20° C) which are placed in turn over the sensor head. Screwdriver adjustments can then be made at the three points marked 'L', 'M' and 'H'.

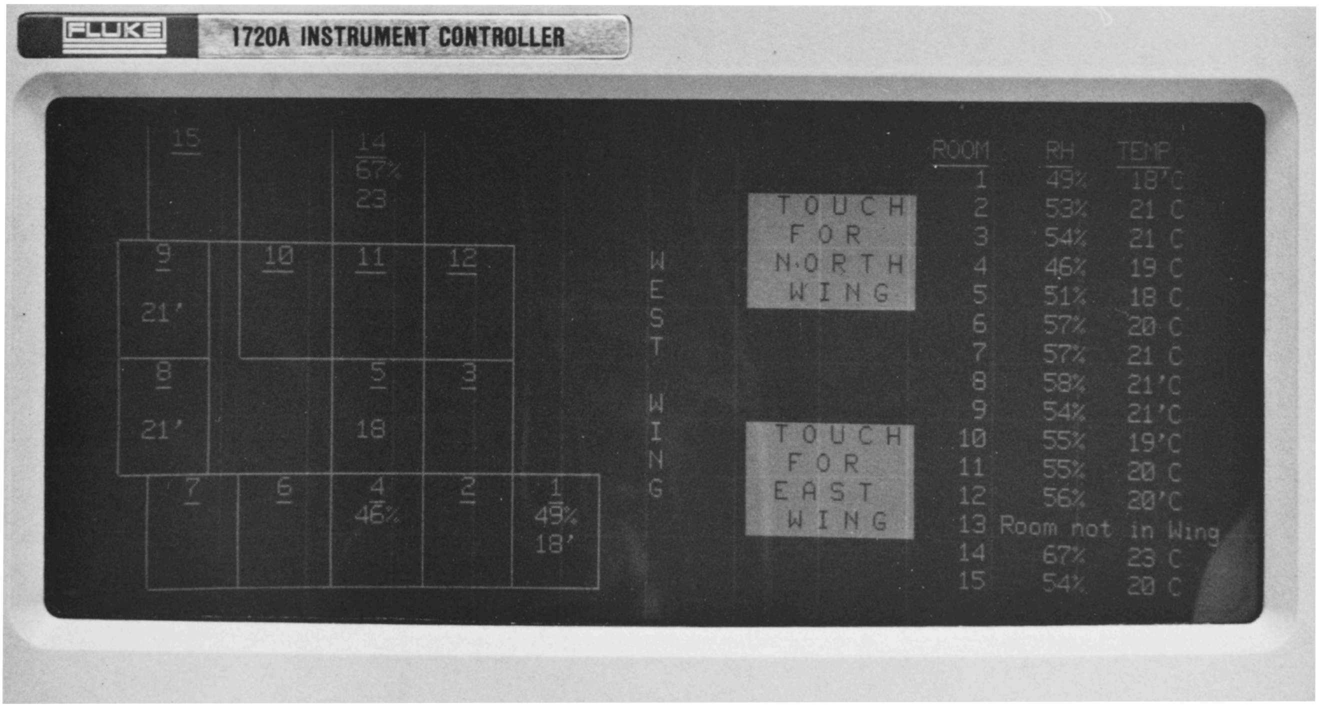

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Figure 13 RH and temperature in the West Wing of the Gallery: a simulated display on the Fluke Instrument Controller. The current data appear in columns on the right. Each room carries an underlined number in the simplified room plan. No other number appears in the room if all is well. But if RH or temperature go off-limit the appropriate figure appears in the room, blinking to attract attention. Thus in Room 1 the figures 49% and 18'C would appear blinking (18'C = 18½°C).

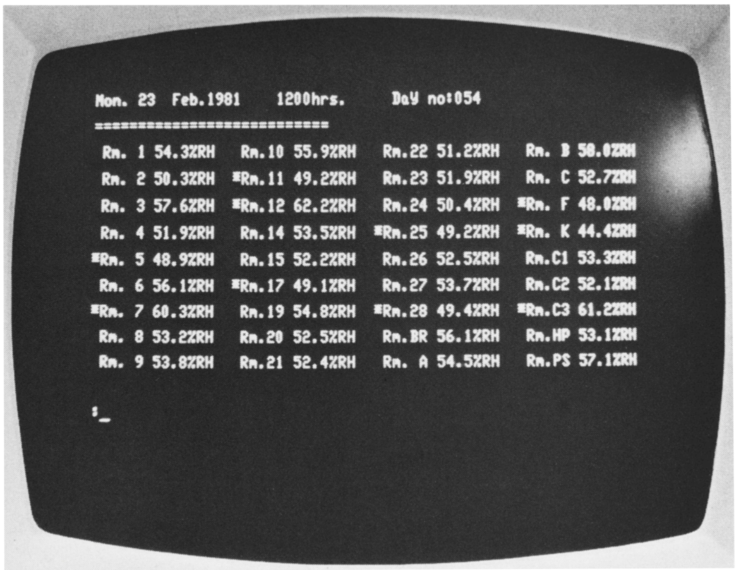
Figure 14 At any time the RH values recorded on the last hour can be displayed. ★ means off-limit value.

Figure 16 A weekly RH off-limit analysis as circulated by the Scientific Department to staff concerned.

corresponding to the RH or temperature sensor in any room and immediately get the figure required. There is also a printer which prints off-limit values as they occur, with the time. If the RH goes above 60% or below 50% this fact is immediately printed and an alarm given. Ingenious though this may sound, it is so far no great advance on the old banks of dials, though it is cheaper and more flexible. It is even a backward step, since, before keying-in a channel number, the operator has first to refer to a table of room numbers against channel numbers. A good display should give the engineer all he immediately needs to know at a glance and also warn him effectively of trouble. Improvements in display are needed and are available (Fig.13 and Plate 8, p.43).

Logger B is connected by cable to a magnetic-tape cartridge recorder in the laboratory, which in turn is interfaced to our computer (Fig.7). Every hour on the hour the logger sends a complete scan of readings up to this recorder (72 channels: 36 temperature, 36 RH). To deal with this information we had to develop programs which, in summary, do the following:

1. Allow a check on the conditions in the Gallery at any time by displaying the previous hour's block of data on the screen. The data are displayed as transmitted: in channel order. But we want the data



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RH OFF-LIMIT ANALYSIS      N.G. WEST WING & NORTHERN EXTENSION
Start: Mon. 1  Jun.1981.  Day nos. 152 153 154 155 156 157 158

(BR = Board Room.  C1-C3 = Cons.Studios.  Hp= Hospital.
PS = Picture Store.)

The symbols against each room are for successive days.
A dot indicates a day within specification (50-60%RH).
If the RH goes outside spec.for 4 or more hrs in any day
the following symbols appear:
                   - = 40 to 49%     + = 60 to 69%
DANGER CONDITIONS:  4 = below 40%     7 = 70% & above
Rm.           Av.  Rm.          Av.  Rm.          Av.  Rm.          Av.
 1 -.------  48%   10 ++....+  58%   22 .......  53%    B .......  54%
 2 ++....+   56%   11 -.---.-  51%   23 ..--.--  50%    C .......  56%
 3 ++.+.++   58%   12 ..-----  50%   24 ...-..-  52%    J ++.++++  59%
 4 .......   54%   14 .......  54%   25 ...-..-  51%    K .......  55%
 5 ..-----   50%   15 .......  55%   26 .......  53%   C1 -------  48%
 6 +.+.++.   57%   17 .......  53%   27 ..--.--  51%   C2 .......  53%
 7 +++.++.   60%   19 .......  54%   28 .+.....  56%   C3 +...+++  59%
 8 .....+.   55%   20 .......  54%   BR ...-...  53%   Hp +....+.  56%
 9 ......-   52%   21 ....+..  54%    A -------  43%   PS ++..++.  57%

Copies to:  Director, M.Wilson, A.Gale, R.French
                                        Scientific Department.
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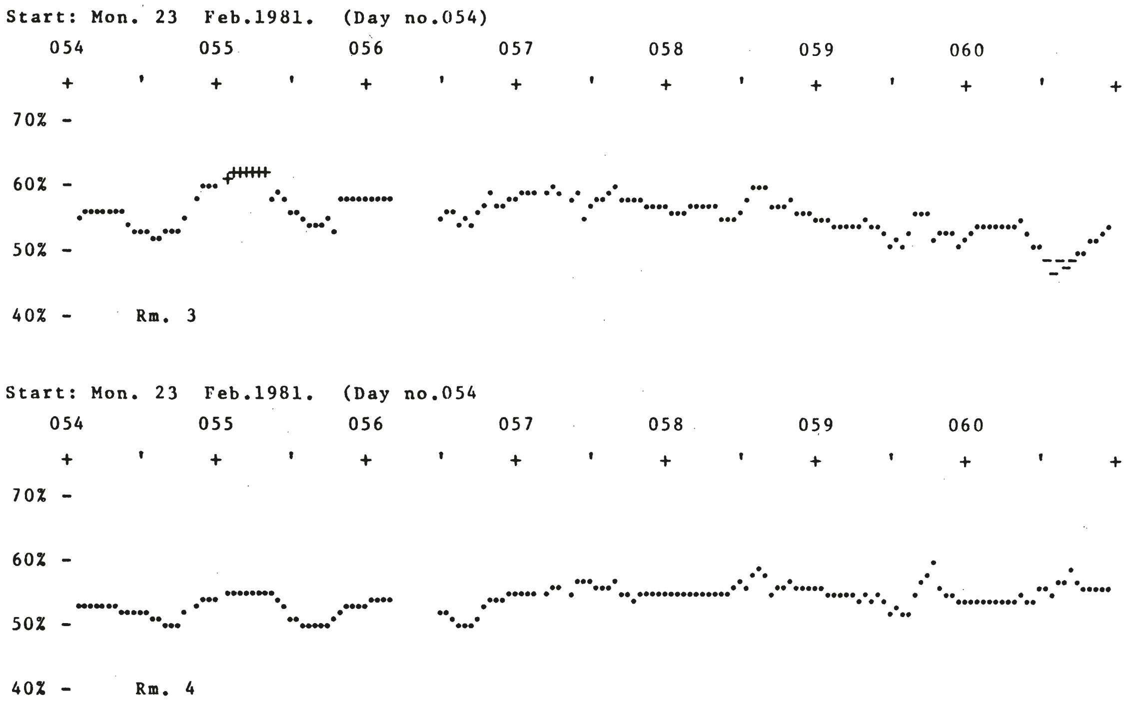

Figure 15 Specimen weekly graphs of RH by the hour. Day number from left to right. A value within spec. is printed as a dot. Above 60% '+' is used, and below 50%, a minus ('—').

by rooms. Indeed we do not wish to deal in channel numbers. Therefore we first wrote a facility to:

2. Convert and re-display this information by room number (Fig.14).

3. Take every week the last week's magnetic-tape record and store it temporarily on disc for ready access. This transfer from tape to disc takes about ten minutes and must be timed so as not to interfere with the data coming up on the hour from below. The tape is then set back to its starting point to begin another week. The temporary record on disc can be examined hour by hour at this stage. But since, in this raw form, it occupies about 70% of one disc it must next be stripped of redundant characters and packed, and also sorted out into a form from which daily records on one channel can be quickly extracted. This packing and rearrangement takes about half an hour on our rather slow computer. When completed the record has been reduced to less than one-tenth of its original length.

4. We must accept that some of the RH sensors will not be reading correctly. Therefore we must be able to correct the data before final storage. Last week's Correction Table now goes on the screen. This table has been previously constructed by going around the exhibition rooms with an accurate instrument and comparing our readings with those currently being recorded on the logger. Alterations can be made to the Correction Table, which is finally stored with the rest of the data. Thus if the logger says that the RH in Room 19 is 59% and we find that it is actually 54%, a correction of —5% is put against Room 19 in the table. Differences of 2% or less are ignored. Channels which are dead or erratic are so marked.

5. For immediate reference it is useful to keep last week's readings in temporary storage on disc, to be overlaid in due course by the following week's.

6. All graphs and tables may now be printed automatically on request (Fig.15). It has been found convenient to produce a very concise summary table (Fig.16), copies of which are sent to all interested staff, both in the Gallery (the Director receives a copy) and in the DoE. To print a complete record in tables and graphs of all seventy-two channels would be uneconomic in time, paper and storage. However a print-out of all rooms with RH less than 50% or more than 60% for more than four hours in any one day is often useful.

7. Finally the record goes into long-term storage on disc. There are more channels than on logger A, so four 8-inch discs are required for the year's record. These occupy the shelf space of one thin booklet.

The present situation

At the time of writing things are just beginning to fall into shape. One can say no more. The goal is always moving forward as technology of the kind we can use gets developed. We started with the simple idea of keeping a log of the environment to be stored side-by-side with our records of colour change. Working together with the DoE we then delved into the inadequacy of RH monitoring in the Gallery's air-conditioning installations. This led the DoE to install a new batch of sensors serving data logger B, which has at present inadequate display, but otherwise is very satisfactory. Our display facilities in the laboratory are superior because we are able to program and use a computer to give us what we want, but they are incidental to our primary purpose, which is long-term storage.

There are three groups of people concerned with the environment in the National Gallery: the curatorial staff, the DoE and the Scientific Department. The curatorial element represents the client role of the Trustees, Director and Gallery staff *vis-à-vis* the DoE. Thus there is a Building and Accommodation section in the charge of a curator which is concerned with DoE-liaison on all aspects of the building, including its internal environment. The DoE is responsible for all air-conditioning and lighting, as well as monitoring, fault-correction, maintenance and new works. The part of the Scientific Department in all this is advisory. We also have a general brief to survey advances in science and technology for elements useful to the care of the Collection.

The net effect is to bring the three groups into a contact of mutual interest in which things are unlikely to go neglected for too long, though 'treble-check' would be too optimistic a description. The Gallery is small enough for only five or six people to be involved in day-to-day discussion and so we are able to keep remarkably free of bureaucratic tangles.

Extension from monitoring to control

The DoE's Fluke logger will have one important control function: if there is an RH excursion above 70% or below 40% then there must be an automatic shut-down of the plant responsible. Obviously it is the sensors on the wall, those which feed the logger, rather than the air-conditioning control sensors, which should be used for this override function. In almost every foreseeable case where a plant malfunction causes RH to go well outside specification the safest course is to shut down the plant completely, including the fans providing air circulation, and, if necessary, to close the exhibition rooms involved as well.

But to operate this scheme we must have confidence in the RH sensors. Otherwise they will be accused of 'crying-wolf' and they will be quietly disconnected from their control function, even perhaps also from their alarm function.

Triple redundancy may be an answer. Every sensor is triplicated, and the circuitry continuously 'polls' this group of three. So long as they agree within preset limits their average goes forward to the logger. But if one of the three falls out of line its signal is disregarded and the average of the remaining two is used. However with the present price of RH sensors this has proved too costly a route to reliability for the DoE.

The only alternative is a very active routine of recalibration, and rapid replacement of faulty sensors.

Before any further exercise of control is handed over to the logger an efficient set of diagnostic sensors is needed in the system. These are sensors placed so as to indicate whether or not all the components of the system are working correctly. Thus a temperature sensor on a heater unit will be able to diagnose failure of this unit. Now, when an alarm is signalled, the diagnostic sensors will be able to pin-point the malfunction so that the operator can take appropriate action. Before this stage is reached it will be necessary to add a microprocessor [4] to the system, not only to select data for display but to handle the display effectively.

None of this, however, extends the control capabilities of the logger. The next step in this direction is a bigger one. A suite of programs covering the more obvious eventualities will have to be written. This calls for considerable knowledge both of air-conditioning and of conservation. To take a rather simple example, the logger finds that the RH in Rooms X, Y and Z has fallen too low. It recognizes that these are all served by one installation whose air washer has failed. It responds by reducing the re-heat on each of the rooms, signals that it has taken this action, and continues to monitor and correct. Note that a particular museum requirement — the primacy of RH control, if necessary at the expense of constant temperature — has dictated the design of this program.

Illuminance

Data logger B, the Fluke instrument, collects temperature and RH readings only, since the control of lighting is quite separate from the air-conditioning operation. Illuminance logging is a matter for the Scientific Department alone. We plan to extend our present group of six meters eventually to cover a representative set of rooms all over the Gallery. These light meters are in the form of 'wall-watching' photocells. That is to say, a photocell is mounted so that it receives light reflected from a section of the picture-hanging wall. Most manufacturers of light-track market cylinder-type light fittings from which the electrical socket and wiring can be removed, to be replaced by a photocell with integrated amplifier (Fig.17 a and b). These units can then be clipped anywhere on existing light-track, though they require their own cable to the logger, and this can be a long run. Long cable runs are in fact an expense which has delayed our own programme. An alternative might be the use of a transponder which, on receipt of a short-range radio signal from the logger, transmits its reading.

Air pollution

Air-pollution monitoring is lagging a little behind in all this, primarily because logging is not required. It is an extravagance to install a continuous monitor for sulphur dioxide when a cheaply-obtained reading accumulated over several months is all that is required, though a monitor might well be useful for experimental purposes. Such a cumulative reading can be obtained by using the West-Gaeke system in which a solution of reagent is held within a semi-permeable membrane [5]. The unit is quite small and can be hidden in a duct. At the end of a set period (say three months) the sulphur dioxide absorbed by the reagent is measured with a standard laboratory colorimetric procedure.

Figures 17 a and **b.** 'Wall-watching' photocell mounted in a cylindrical light-track lighting unit (Rotaflex). The mains electrical fittings have been removed and a photocell with built-in amplifier placed in the lamp-socket position. The unit can be clipped anywhere on the light-track. It can just be seen at the nearest point on the light-track in (**b**). A mask at the front of the cylinder defines the area covered by the photocell.

For good or ill?

It has been recognized for some time that humidification is required during the winter heating period if only to keep exhibits as safe as they were fifty years ago. Obviously we can and ought to keep them not only as safe but a great deal safer than they ever were. This involves control of RH within reasonably narrow limits, and also control of certain other factors such as air pollution. Both these requirements are best fulfilled by installing ducted air-conditioning.

But air-conditioning has its dangers. A malfunction may rapidly raise or lower the RH to dangerous levels. Therefore the whole system must be very carefully and continuously monitored. An inadequately supervised system is likely to do more ill than good.

The writing of computer programs (software) is still considered an esoteric and highly specialized craft. But with the imminent arrival of very cheap computers in schools the position will rapidly change. If a computer is to be used in a perfectly standard manner, such as for book-keeping in a small business, then the buyer need know nothing and need spend almost nothing on software. But special needs require special software. Programs are available for helping air-conditioning installations economize on fuel, but these are remote from museum needs.

For any degree of automation in air-conditioning for conservation in a museum special programs must be written, and these will be expensive in time and money.

But even more advanced and specialized systems have been developed for large utilities such as power stations and chemical plants. Such systems have become crucial to safe and economic operation. To argue in purely economic terms, there is as much capital tied up in a major picture gallery as in a nuclear power plant, and the welfare of this capital asset is equally dependent on first-class monitoring and control.

Notes and references

1. BULLOCK, L., 'Reflectance Spectrophotometry for Measurement of Colour Change', *National Gallery Technical Bulletin,* **2** (1978), pp.49 – 55.
2. THOMSON, G., MILLS, J. and PLESTERS, J., 'The Scientific Department of the National Gallery', *National Gallery Technical Bulletin,* **1** (1977), Fig.11, p.27.
3. A bit is the basic unit of information. 8 bits here mean 8 on/off signals sent in succession as part of an agreed code for numbers and letters.
4. The microprocessor has been described as a 'computer-on-a-chip'. It is coming to be used on all instruments or machines which require complicated or interactive control.
5. REISZNER, K.D. and WEST, P.W., 'Collection and Determination of Sulfur Dioxide Incorporating Permeation and West-Gaeke Procedure', *Environmental Science and Technology,* **7**, 6 (1973), pp.526 – 32.