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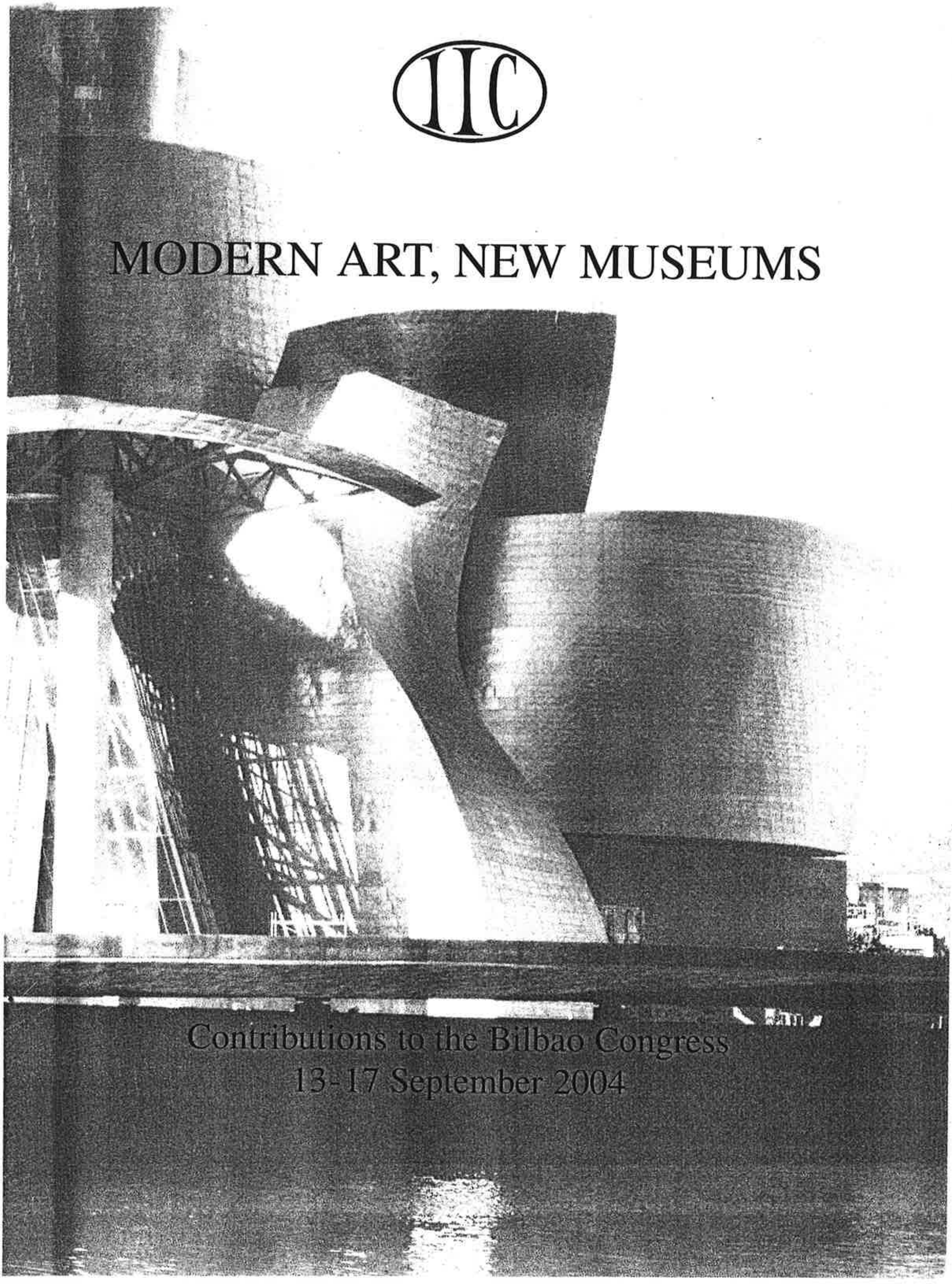
MODERN ART, NEW MUSEUMS



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LAUNCHING A NEW MUSEUM: UPWARD DISPLACEMENT AIR-CONDITIONING AND COMPUTER-CONTROLLED DAYLIGHT ILLUMINATION

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ABSTRACT
This contribution describes a period of 18 months around the recent opening of the Pinakothek der Moderne in Munich (Germany). As so often happens, building work was delayed but the dates for the opening ceremony were fixed. While thousands of highly sensitive objects were being moved onto the site, the building still presented many technical defects. This required conservators and conservation scientists to control and ensure the functionality of the building within the framework of preventive conservation. Special attention was given to the upward displacement air-conditioning in the first-floor galleries and their computer-controlled daylight illumination system. The article assesses both systems in terms of functionality and use in preservation. *In situ* data are compared with experimental data from a test room, with simulations, and with data from conventional air-conditioned and artificially lit galleries in the same building. Results of dust, pollution and noise measurements are included.

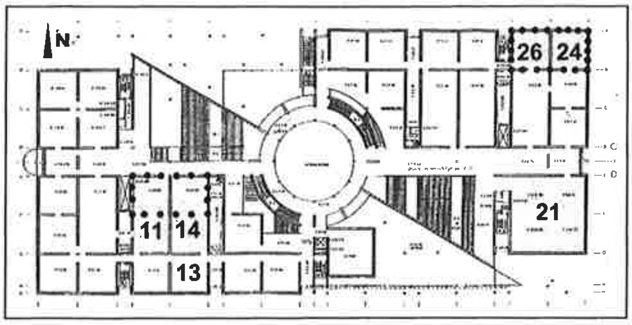

Fig. 2 Ground plan of the first-floor galleries (for an explanation of gallery numbers see text). Dotted lines mark the roof layout.

INTRODUCTION

In 2002, the third Pinakothek in Munich, called the Pinakothek der Moderne (PdM), was opened [1]. The building (Fig. 1), designed by the architect Stephan Braunfels, houses four major collections presenting modern and contemporary art (Sammlung Moderne Kunst), works on paper (Staatliche Graphische Sammlung), architecture (Architekturmuseum der Technischen Universität München) and design (Die Neue Sammlung). The modern and contemporary art are mainly located on the first floor (Fig. 2); the other three collections are on the ground floor and in the basement.

This contribution focuses on the six months before, and the first year after, the opening of the building on 16 September 2002. Planning started in 1992, and building work in 1996. Economic and technical difficulties delayed the opening. Finally, the date of general elections defined the date of opening of the museum, a few days before the election. This political decision created pressure on everyone involved and had strong conservation implications. Although many technical defects were still being discovered, the collections started to move in from 21 May. In addition to the many conservation-related aspects of these 18 months, the air-conditioning (AC) and the lighting concept of the first-floor galleries are discussed. Both are assessed in terms of preventive conservation. The paper aims to pass on practical experience which may be useful for other conservators in a similar situation.

THE AIR-CONDITIONING CONCEPT

The conservation community has learnt from the study of mediaeval churches and castles, from mines where objects were evacuated during World War II, and from nineteenth- or early twentieth-century museum buildings, that the stability of room climate is the major prerequisite for the preservation of hygroscopic objects over long periods, even if the absolute values deviate from recommended conditions. The Doerner-Institut therefore recommends keeping collections within a narrow climate range [2, 3]. This is a problem, however, when the architecture is 'wrong' from the point of view of preservation and, additionally, a more complicated technical task in day-lit galleries, such as those on the first floor of the PdM [4, 5].

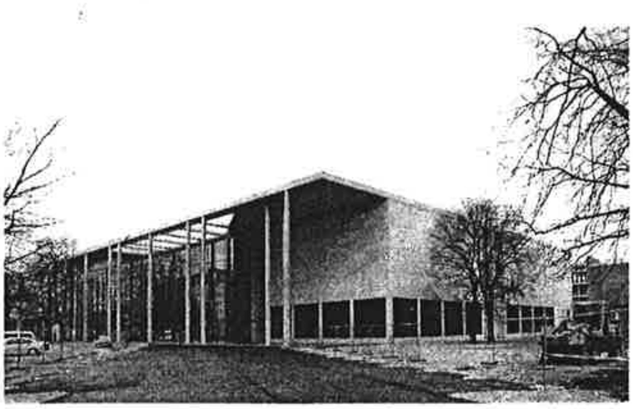

Fig. 1 View of the Pinakothek der Moderne from the south-east. *Photo: S. Forster, Bayerische Staatsgemäldesammlungen*

There is a modular architectural concept for the first-floor galleries which has created rooms of 10 × 10, 10 × 20 and 20 × 20 m (Fig. 2). The 36 galleries are divided into two main climate zones. These main zones are organized into six and seven sub-zones respectively. Two huge staircases and a rotunda in the middle of the building form additional main zones. Due to this open architectural concept, the zones are not defined by any closed doors. In every room, a trench 20 cm wide and 8 cm deep runs along the walls. It functions as a design element separating the walls from the grey terrazzo floor. The height from the floor to the coffered ceiling is 5.80 m. The coffered ceiling itself, which houses lay-lights, has a height of 1.80 m.

As suggested by Hilbert in 1992 [6], an upward displacement air-conditioning system (UDAC) was carefully considered, tested experimentally, modified according to the test results and finally selected. Based on experiments in a 1:2 scale test room in 1993, conditioned air is introduced from the trench (85%) and to a lesser extent from the ceiling at a level of 5.80 m (15%). This separation of the incoming air turned out to be crucial in avoiding air layering, which would result in considerable temperature and humidity gradients from the floor to the ceiling. The zone below the lay-lights in the coffered ceiling, at a level of 7.60 m, takes up the used air. The air exchange rate is three or four times per hour, whereby 20% of the air is replaced by fresh air. The fresh air is taken from the roof of the building, filtered centrally (with coarse and fine dust filters and an active carbon filter) and pre-conditioned using heat recovery. Final heating takes place in each sub-zone according to the current requirements in the building. More locally, additional double-step filtering helps to reduce the dust intake. Relative humidity (RH) and temperature are measured continuously by sensors at a height of 2.80 m built into the exhibition walls close to the objects. An attempt is made to keep the room climate within a narrow band of ±3% RH and ±1 K. The cost of the air-conditioning systems for the whole building was 6.5% of the total building cost of 121.5 million

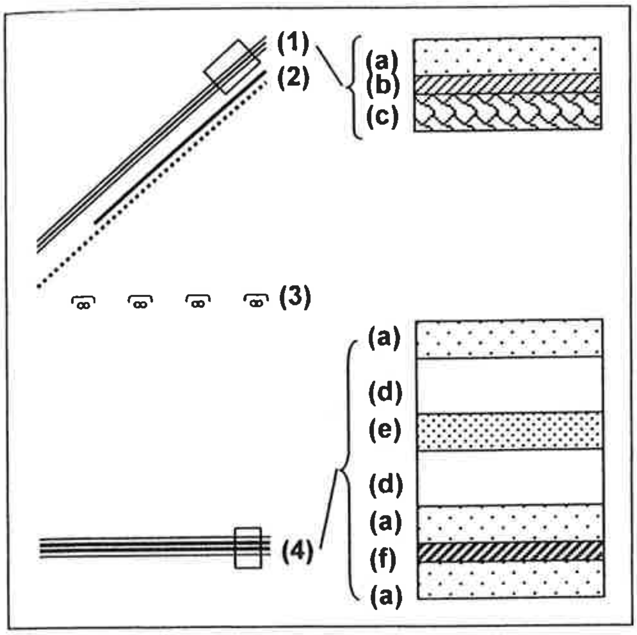

Fig. 3 Schematic representation of the roof glazing. (1) Outer glazing: (a) white glass, (b) adhesive, (c) diffusing glass. (2) Shading screens, semi-transparent white (···) and opaque white (—). (3) Fluorescent tubes and reflectors. (4) Lay lights with (a) white glass, (d) gas filling, (e) sandblasted white glass and (f) double layer PVB (polyvinylbutyral) UV-film.

euro; the individual cost of the UDAC is not available. Further technical details are given elsewhere [7].

THE LIGHTING CONCEPT

The lighting design of the new museum closely follows that of the other day-lit museums: the Alte Pinakothek (AP) and the Neue Pinakothek (NP) [1]. We believe that pure daylight is superior to any other kind of illumination. Only daylight provides the changing light conditions which guarantee the vivid appearance of the objects. Daylight, however, is the most difficult type of light to use: its control and conservation demands are difficult to reconcile.

In the PdM, every first-floor gallery has a counterpart in the roof space above. This space contains technical equipment such as ventilation and artificial light, as well as a double set of textile screens. A transparent white screen reduces the incoming light, while a second, opaque, white screen permits the galleries to be darkened to 10 lux outside opening hours, or for special exhibitions.

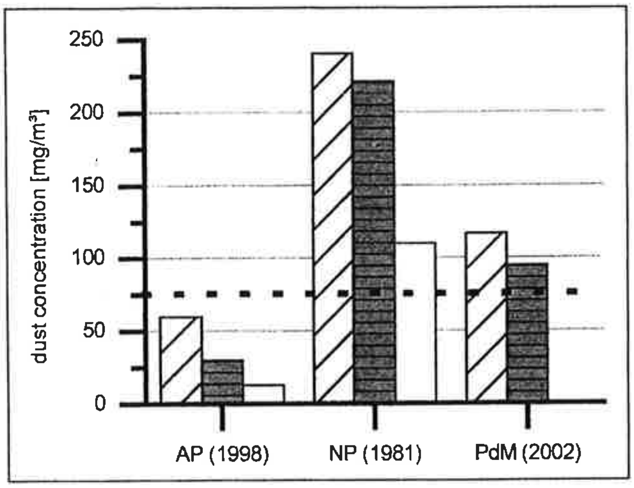

Fig. 4 Results of repeated dust measurements in the Pinakotek der Moderne (PdM) and comparison with values recorded at the Alte Pinakothek (AP) and the Neue Pinakothek (NP). Values in parentheses are dates of the (re)opening of the galleries shown. Recommended value (----) from [8].

To provide excellent colour rendering and to fulfil conservation and security requirements, a special multi-function system for the lay-lights and the roof glazing has been developed (Fig. 3). This includes UV-protection, multiple light diffusion, thermal insulation and security. As a result of the structured glass, the transparent textile screens, the sandblasted lay-light glass, the white-painted walls within the roof and the coffered ceiling, as well as the considerable depth of the coffered ceiling itself, the incoming light is strongly diffused. In this way, the shadows of picture frames and dark corners in the galleries are avoided. Two control sensors for every 100 m² constantly record the illumination level, and allow the screens or the artificial light sources to react to any change in the outside lighting conditions. The total cost of the lighting system, the glazing of the lay-lights and the roof was 3.7% of the total building cost.

THE SIX MONTHS BEFORE OPENING

Dust and pollutants

Because most of our modern and contemporary art objects have unprotected surfaces which are therefore delicate, dust measurements were conducted. These were compared to those of the AP and NP (Fig. 4). In the period reported, the large amount of dust in the PdM was clearly caused by continuing building work in the galleries. Daily wet cleaning improved the situation. Additional dust was absorbed by the double filters described above. These were replaced shortly before opening. To our surprise, the NP showed much higher levels of dust than both the PdM and the AP. Presumably, this is due to the different ages of the AC systems (see Fig. 4).

Exterior and interior air pollutants were measured over two months (Fig. 5). While ozone (O_3) could be absorbed highly effectively by the active carbon filters, the outdoor levels of nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) were only reduced by 45–78% [10]. However, all values recorded were below those recommended [9].

Room climate

As in any new building, major and minor technical malfunctions of the AC occurred in the period after the system came into operation in 2002. RH values showed unexpectedly unstable behaviour. The cause of this problem was traced to the room sensors mentioned above. Although they had been calibrated repeatedly, most of them showed *in situ* RH values at variance with those of a calibrated reference hygrometer. These sensors are used not only for monitoring but also to control the AC units of the 13 sub-zones described. Each sub-zone has several sensors and the RH is controlled by the mean of these sensors.

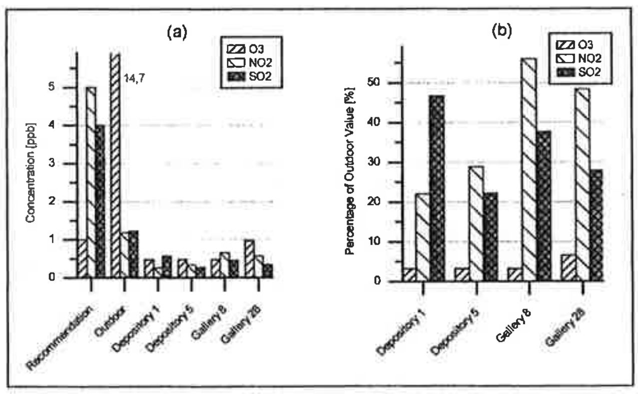

Fig. 5 Absolute (a) and relative (b) recorded pollution levels in the Pinakotek der Moderne. Recommended value from [9].

Consequently, wrong absolute RH values of individual sensors lead to wrong mean values. As a result, local AC units reacted: in the worst case, one sub-zone needed humidification while the neighbouring sub-zone required de-humidification. In reality, the conditions in both sub-zones turned out to be quite similar when checked with a reference hygrometer, and this confirmed the fact that there was actually no need for either humidification or de-humidification. We therefore decided to check all 123 room sensors regularly against a reference hygrometer and to compensate for the differences measured by the introduction of individual compensation factors for RH and temperature in the control software. This resulted in a considerable stabilization of the climate of the first floor and, ultimately, a notable reduction in cost.

To verify the experimental data and to check the functioning of the UDAC, the climate in three individual galleries (13, 14 and 21) was measured. The air velocity, temperature and RH were recorded for a cooling situation (summer), a heating situation (winter), and the isothermal case. Along each wall and in the middle of the room, five groups of four sensors were placed. Depending on the size of the objects on display, the sensors were located at a height between 0.40 and 4.00 m. The results shown in Figure 6 allow the following conclusions to be drawn:

1. As is typical for a UDAC, the cooling and the isothermal examples showed air velocities of less than 5 $cm.sec^{-1}$, whereas values between 15 and 25 $cm.sec^{-1}$ were observed for the heating case (Fig. 6A). Compared to a conventional AC, these air velocities are far lower. The low air velocities of the UDAC guarantee that electrostatic charging and deposition of dust on surfaces are reduced.
2. The largest RH gradient (ΔRH) could be observed for the cooling example (-1.5% at a height of 4.00 m), while the deviation for the heating and isothermal cases stayed below 1% (Fig. 6B).
3. The temperature gradient (ΔT) measured between 0.40 and 4.00 m is below 0.5 K in all three cases (Fig. 6C).
4. Within one room, the air conditions varied. A maximum ΔRH of 2.5% at a height of 4.00 m could be observed for the southern outer wall (Fig. 6D). The centre of the room — around 5 m away from the trench — showed the smallest ΔRH.
5. Evaluation of the data suggests that layering of the air in different conditions can be ignored.
6. The experimental data in the 1:2 scale model room from 1993 do not totally correlate with the values measured in 2002 (Fig. 6A-C). However, the *in situ* measurements clearly support the results of the 1993 experiments and the expectations of the UDAC concept.

Noise

While the galleries were still empty of visitors, unpleasant noise was noticed in most of them. The air supply turned out to be responsible for low-frequency noise, while the active smoke detection system produced noise of very high frequency.

Light

A major fault of the architectural design, at first unnoticed, became obvious on the first floor. Pairs of neighbouring galleries — which may contain very different art objects — are covered by a single roof space. This is the case, for example, for galleries 11 and 14 and for 24 and 26, as shown in Figure 2. The roof space usually contains groups of five south- and five north-facing screen units. Each group is controlled by one of two sensors (north or south) in the two galleries below. It is not possible to move the screens independently for each gallery and this major design fault has serious conservation consequences. For example, Gallery 24, containing light-sensitive works of art by Joseph Beuys which require a maximum illumination level of 70 lux, is next to gallery 26, containing paintings by Cy Twombly which are allowed a maximum light level of 300 lux. Because both galleries are covered by a single roof space, they are either at 300 or at 70 lux. To overcome this, the 25 lay-lights (each measuring 2 × 2 m) in the Joseph Beuys room were partially darkened by the use of costly, non-flammable, semi-transparent fibreglass.

In the weeks before opening, three more major technical problems had to be solved. During opening hours the screens, which closed and opened frequently to follow the changing light conditions outside, no longer took up their exact positions. The costly installation of position controllers on all 508 screens solved this problem. Second, during rapidly changing weather conditions a considerable delay in the movement of the screens was observed. To prevent the galleries being without enough light, which could last up to seven minutes as a result of the centralized building management system, artificial light had to be discreetly added. This problem could be solved by changing the software. Finally, the initial selection of Philips 940 fluorescent tubes turned out to be problematic. The hue of the mixed daylight and artificial light turned out to be much too red, and this was easily visible in the white-painted galleries. To our surprise, this

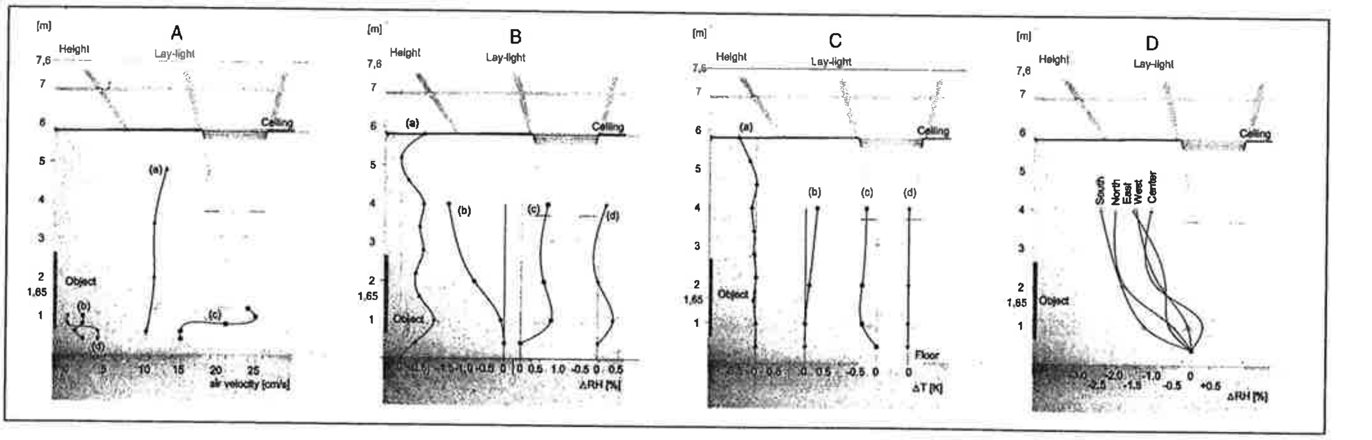

Fig. 6 Results of air condition measurements at different room heights. The values of air velocity (A), deviation in relative humidity, ΔRH (B), and deviation in temperature, ΔT (C), as measured in the 1:2 scale experimental model room (a) and *in situ* in Gallery 13 (west wall) for (b) the case of cooling, (c) the case of heating, and (d) the isothermal case. Diagram D shows the results for deviation in relative humidity, ΔRH, at different room heights on all four walls and in the centre of Gallery 13 for the case of cooling.

effect was caused by the Philips 940 tubes, which produce reddish light when strongly dimmed. Replacement by Philips 960 tubes made the light unacceptably cool during evening opening. A mixture of 75% Philips 960 and 25% Philips 940 lamps finally solved this problem.

As soon as the mechanics of the screens worked properly, the software, which had been tested exhaustively in a 1:1 scale model room, kept the light levels within the required range. For most of the opening hours, it was possible to achieve daylight illumination with an average of 300 lux. Artificial light is quickly added if the level falls below 214 lux. In a second step, after a time-delay, the screens open or close if the illumination is below a certain level. The time-delay, like all other values, can be easily set in the control software. This software even allows the light level to be controlled at 70 lux — a level at which daylight is usually regarded as uncontrollable and therefore an inappropriate choice.

THE FIRST YEAR AFTER OPENING

Dust

The architectural design is in keeping with the conservator's view that visitors should leave behind most of their dirt and dust before they reach the galleries. In the PdM, this is achieved in the huge, covered entrance area (Fig. 1), the large rotunda and the long staircases. Visitors have to walk about 110 m before they enter the galleries on the first floor. Nevertheless, conservators caring for the galleries report considerable deposition of dust on all art objects up to a height of 1 m, especially on horizontal surfaces. Both the 1.3 million visitors during the first year (who lose, for example, skin and clothing particles) and the UDAC may be considered as possible origins for this dust. As regards the latter, it is supposed that the low air impact is not sufficient to transport the dust up to the ceiling where the air is taken out and filtered. Common cleaning activities, such as using ostrich-feather dusters or vacuum-cleaning, distribute the dust rather than reducing it; daily wet cleaning turned out to be more effective (Fig. 4).

Climate

During the six weeks before opening, the climate conditions in all first-floor galleries finally stabilized. This is understandable for the main parameter, RH. The 400 m^2 Gallery 21, with its entrance open to the huge eastern staircase, showed minimum to maximum RH values between 50 and 52% in August 2002. During the opening week in September, with more than 281,000 visitors, this minimum to maximum range widened to 48–52%. The continuing high number of visitors explains values between 49 and 52% in October. One of the galleries in the architectural museum on the ground floor, which has conventional AC, showed a wider range (between 47 and 55% RH) in the same period.

Figure 7 shows the frequency distribution of the change in RH between two sequential measurements. It is obvious from the standard deviation (0.19, 'Std. abw.' in Fig. 7c), that the RH in Gallery 21, equipped with UDAC, stays very stable compared to the room with conventional air-conditioning in the architectural museum (0.35, see Fig. 7d).

Following the 1992 design brief for the museum, the UDAC system was designed to maintain RH of 55 ± 3 % and temperature of 20 ± 2°C. Due to the materials on exhibition, it was decided to lower the RH to 50 ± 3%. Because the AC systems were not designed to maintain these conditions throughout the year, including the humid late spring and summer periods, we finally agreed to temperature compensation: during the summer, the temperature goes up to 24°C and in autumn, down to 20°C again. Within the compensation steps of 0.5 K, temperature shows very stable behaviour for the UDAC system as well as for

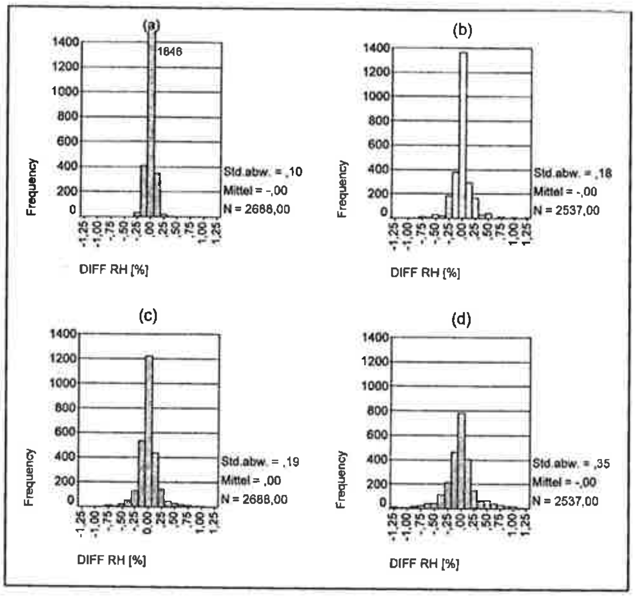

Fig. 7 Frequency distribution of the change in RH between two sequential measurements (DIFF RH) in Gallery 21 (with UDAC) in (a) August, (b) September and (c) October 2002. For comparison (d), one room of the architectural museum (with conventional AC) in October 2002.

the conventional AC. The temperature compensation also led to a considerable reduction in cost.

Regular checking of the mid-term stability of the control sensors revealed a considerable shift. It was therefore considered necessary to check the sensors every four months and to determine ΔRH and ΔT for each of them. The time required for a check of this kind is between 60 and 75 hours.

In summary, the UDAC kept the room climate within the narrow specifications. The high performance of the system was not noticeably affected by the 1.3 million visitors during the first year. Practical experience within this period confirms that UDAC is superior to conventional AC.

Noise

Depending on the individual gallery, recent measurements yield a noise level of 42-47 dB with visitors and 37.8-48.6 dB without visitors [11]. Although the air jets of the active smoke detection system have been improved, the noise level is still above the value of 38 ± 2 dB recommended by the Doerner-Institut.

Lighting

During the week of the opening celebrations and for some weeks after, the shading system worked well for both clear and cloudy skies (Fig. 8). To the delight of the public, who have been unaware of the occasional addition of artificial light, the first-floor galleries were homogeneously day-lit for most of the opening hours. The remaining problems of the central building management system were resolved and the use of the complex lighting control software became a daily exercise. With growing confidence in the new building, special exhibitions were mounted which included electronic media and photographs, light-sensitive installations and self-illuminated objects. The need for zero lux (for electronic media) and for rooms with a low level of illumination (70-100 lux) made the fibreglass screen a tool in daily use. This solution became even more necessary when it was discovered that the promised minimum level of 10 lux turned out to be 100 lux during bright summer sunshine.

There were other time-consuming problems, such as the manually-controlled light-screens in the corridors, and interface problems between the smoke protection dampers and the shading

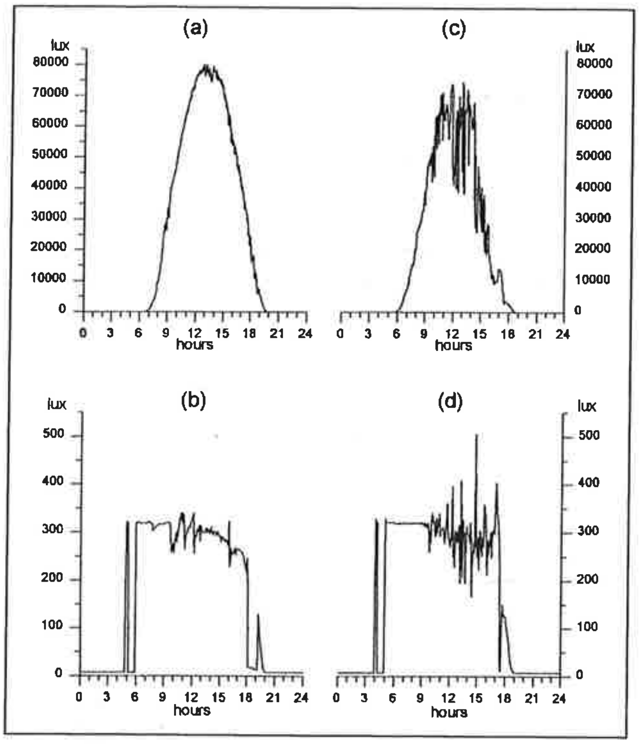

Fig. 8 Outdoor (a & c) and indoor (Gallery 11/14, b & d) illumination levels under clear (a & b) and cloudy (c & d) sky.

system. In addition, defects in the mechanical parts of the textile screens, and the frequent use of artificial light alone during repairs, detracted from the visitor's experience and undermined the idea of a day-lit museum. At the end of the 18-month period, most of these problems have largely been overcome. The difficulties encountered, however, made it clear that continual maintenance of all mechanical parts of the system is necessary Service contracts which provide a response at short notice are essential to keep complex lighting systems working, in order to create the lighting conditions required and to guarantee the quality standards required by the museum in the long term.

CONCLUSIONS

These observations allowed us to formulate several general conclusions, which may help others to avoid similar situations:

1 Conservators tend to expect that the building workers will move out and that they and the objects will then move in. In practice, these processes work in parallel: you move in while the builders are still working. This causes serious problems for conservation and, most importantly, security. Conservators usually underestimate the complex task of launching a new museum with all its technical facilities. It should be noted that the date for the opening of the building is never defined by the needs of the objects or the wishes of the conservator.

2 Building a museum is an interesting, challenging and complex task. It requires the professional involvement of the in-house conservators from the outset: their participation is indispensable. Wrong decisions made early on (which are frequent) can often not be corrected later. Careful planning with enough time allowed, experiments in test rooms and simulations give effective support to the planning process. Future development of the collection should be taken into account.

3 Our experience of upward displacement air-conditioning is excellent so far. For the greater part of the collection, the system maintains RH and temperature conditions within a narrow band. The inertia of the system, often seen as a disadvantage, turns out to be of great practical use. The air inlet located directly below the objects — in our case, via the trench — is obviously less of a problem than originally supposed. However, it is important to be aware of the increased deposition of dust. In the future, UDAC may be supplemented by wall heating and indirect daylight illumination to create more stable conditions and to reduce running costs.

4 Complex control systems, which today are part of every new or renovated old museum, require highly trained staff. In addition, the long-term functionality of the building depends on well-maintained technical facilities, which require external service and maintenance contracts which can be invoked at short notice. These are an element in the running costs of the museum which is often overlooked. As a rule, the running costs over 10–15 years are equal to the original investment.

5 In the day-to-day control of light and climate, conservators play an important part. These tasks cannot be fully delegated to, for example, technicians. In our experience, they judge conditions in the galleries by what their machines tell them, rather than from the actual conditions around the objects.

6 While the security system is controlled by a separate computer system, the central building management system controls light and climate. In the future, we would prefer to separate these two tasks, even if it means having an additional computer system. This is mainly because interface problems tend to be underestimated.

7 After the museum has opened and the builders have moved out, it remains the task of the museum staff to detect technical failures, and sometimes even to find a solution. Because this involves issues of preventive conservation, it depends mainly on the competence and expertise of the museum's conservators.

MANUFACTURERS

RH measurements

Portable Hygropalm-1 with HygroClip-S: Rotronic Meßgeräte GmbH, Einsteinstrasse 17-23, 76275 Ettlingen, Germany.

Humbug datalogger: Hanwell Instruments Limited, 12 Mead Business Centre, Mead Lane, Hertford SG13 7BJ, UK.

MoniLog HTD 9460 datalogger: SMT & Hybrid GmbH, An der Priessnitzaue 22, 01328 Dresden, Germany.

Dust measurements

Staubmeßgerät Modell 1.108: Grimm Aerosol Technik GmbH & Co. KG, Dorfstrasse 9, 83404 Ainring, Germany.

Light measurements

Illumancemeter T-10: Minolta Europe GmbH — Industrie-Messtechnik, Minoltaring 11, 30855 Langenhagen, Germany.

Elsec UV Monitor Type 762: Littlemore Scientific Engineering Co., Railway Lane, Littlemore, Oxford OX4 4PZ, UK.

Pollution measurements

Passive diffusion tubes (SO_2, NO_2, O_3): Gradko International Ltd, St Martins House, 77 Wales Street, Winchester SO23 0RH, UK.

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11 Akustik-Ingenieurbüro Moll GmbH (Berlin), personal communication (2003).

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