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Article

Microclimate of the Natural History Museum, Vienna

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Abstract: Climate change increases the importance of maintaining environmental conditions suitable for preventive conservation within museums. The microclimates at the Natural History Museum of Vienna, a large national collection housed within a classical building, were studied using >200 data loggers placed out from mid-2021 to provide thermo-hygrometric measurements at 15-minute intervals. Daily mean temperatures showed exhibition halls typically the warmest rooms; well heated in winter and with open windows on summer days. They may become even hotter than the outside temperature. In winter, most areas of the museum are very dry, as heating lowers the relative humidity, typically to 25–35% for the coldest season. Opening hours impose daily and weekly cycles on internal climate. There was little difference between sunny and shaded parts of the building or adjacent offices, corridors and depots. Similarly, the micro-climate at the floor resembled that of the room air at ~2 m elevation. Mechanically controlled climates in cold storage areas maintain 10 °C and relative humidity ~50%, but this has become increasingly difficult in hot summers. While there is little apparent damage to the collection, at times the museum can have an extreme indoor climate: very hot in the summer and dry in the winter.

Keywords: indoor museum environment; climate monitoring; climate change

1. Introduction

The 20th century saw the development of the concept of preventive conservation [1] and an increasing interest in the climate of museums. This led to the publication of key works on museum climates, such as Garry Thomson's *The Museum Environment* of 1976 [2] and later Dario Camuffo's *Microclimate for Cultural Heritage* of 1998 [3]. The climate of museums was increasingly well-monitored [4–7] and able to take advantage of the recent availability of sensors and cloud based systems [8]. In an age where damage from pollutants within acid rain were of great concern, it is little wonder that pollutants within museum air were also of rising interest [9] and is very much a focus of many contemporary studies [5]. These were ultimately joined by concerns about the impacts of a changing climate [10,11] and the relevance of an applied representation of weather parameters as seen in terms of heritage climatology [12]. This has placed the microclimate of the heritage environment as a major feature of research and a practical challenge for heritage management [13]. Climate change has meant increasing interest in the way in which outdoor climate propagates indoors [10,14].

Future changes in indoor temperature and relative humidity, although perhaps just a few degrees or percent, seemed likely to especially affect indoor pests such as insects and fungi [15–17]. However, even contemporary environmental conditions in the heritage environment are not always well understood. While temperature and relative humidity have long been monitored indoors, the

availability of inexpensive microsensors have allowed more detailed pictures of the indoor climate, which can be seen in the measurements from a number of locations [4–7]. While such campaigns have established variation across museums, it has often been difficult to relate observed outcomes to climate given the changing nature of collections, visitors and exhibited materials. This study looks at the climate of a major historic museum building with the largest natural history collection in Austria, to explore the climate of different areas of a museum and how it changes over time and space and compares this with that outdoors. While the monitoring was undertaken to understand the presence of insects and fungi, it has a wider relevance to the general preservation of sensitive materials.

Increases in temperature, humidity, airspeed, solar radiation and pollution in a changing world [18] heighten the risk of degradation and damage to cultural and natural heritage. In this context, an accurate and efficient access to microclimate information and monitoring of microclimate change, to better understand the decay of heritage are of considerable importance for the sustainable conservation of heritage.

The current study of the Natural History Museum, Vienna (Figure 1) forms part of a more extensive programme examining threats of a changing climate to museums [19]. The presentation here examines this large national collection in a classical, though modified, building with easy exchange of visitors and air between the exhibition rooms. It explores the differences between the floors that show a range of uses beyond just acting as exhibition spaces. It thus considers the needs of storage spaces, offices, archives, libraries etc.

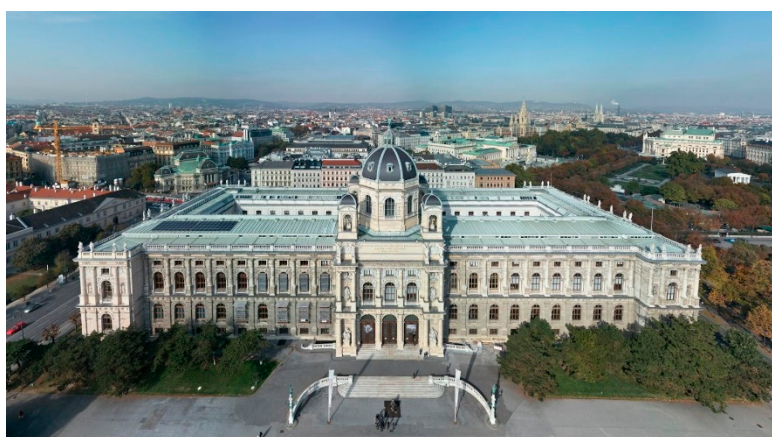


Figure 1. Aerial view of the Natural History Museum in Vienna, Austria. NHM Wien © GeoPic.

2. Materials and Methods

2.1. *The Natural History Museum in Vienna*

The Natural History Museum of Vienna is a research museum and dates back to the imperial collections of the 18th century, with its collections organised by the geologist Ferdinand von Hochstetter [20]. It is found in the Inner City on the Museumsplatz. The current building was inaugurated on 10 August 1889 and presently has 39 large exhibition rooms, which display more than 100 000 objects. At the Mezzanine floor (F1) minerals, rare fossils, huge dinosaurs and unique prehistoric findings, such as the famous Venus of Willendorf, are on display. On the first floor (F2) mammals, birds, insects and other arthropods are presented, most of the objects in historic wood and glass showcases. The building has a basement, a ground floor and four further floors, including the modernised attic [21]. The total area of the museum is 8460 m², which additionally includes offices, laboratories, libraries and storerooms (Table 1). The building is some 170 m long and 70 m wide, comprising two courtyards that are each surrounded by working, storage and exhibition rooms. In total, the museum has 900 rooms (occasionally referred to by their numbers in the text). It is home to 30 million objects available to more than 60 scientists and numerous guest researchers who carry out basic research in a wide range of topics related to human, earth and life sciences. As a result, the NHM Vienna is one of the largest non-university research institutions in Austria, one of the ten

largest natural history collections in the world and an important centre of excellence for all matters relating to the natural sciences.

Table 1. Description of the six levels, including a cooled storage area, sampled across the Natural History Museum in Vienna, Austria. Note: collections investigated are denoted by italic script.

Floor No	Description	Floor Code	Collection type and room use	Climate control	Data loggers	Data loggers at floor level	Visitors present	open windows
F4	Attic, modern	OG3	archive, library, <i>botany</i> , <i>entomology</i> , offices <i>mammal</i> , library,	HVAC	37	4	no	no
F3	historic	OG2	<i>entomology</i> , <i>anthropology</i> , <i>botany</i>	only heating	42	5	no	partly
F2	historic	OG1	exhibition, <i>bird</i> , library	only heating	44	5	yes	yes
F1	Mezzanine historic	HP	exhibition, offices	only heating	36	5	yes	yes
F0	Ground floor, historic	TP+EG	library, taxidermy studio, offices	only heating	40	0	no	no
FB	Basement, historic	K	technical rooms, storage	no control	32	0	no	no
FC	Cooled storage, modern		storage	HVAC	5	0	no	no

New spaces were required by the late 20th century, in the face of a growing number of acquisitions to the collection. This problem was partly solved with the construction of an underground storage area, immediately adjacent to the museum, with four underground levels. It was built at the time of the construction of the subway line U3 and completed in 1990. This new storage area allowed sensitive elements of the collection to be kept in a climate-controlled environment. Some of these underground storage areas house the valuable prehistoric, bird, mammal, reptile and entomological collections that are cooled with a HVAC system to 10 °C or 16 °C to prevent damage from insect pests. In the summer, additional dehumidifiers are necessary to regulate the humidity. Further, a roof conversion was carried out between 1991 and 1995 that also created new storage, libraries, archive and working areas in the attic of the building, by effectively adding another floor. In the attic, a few rooms have an HVAC system to regulate the climate (cooling, humidification and dehumidification).

2.2. Instrumentation and Data

A total of 250 MostraLog data loggers were ordered and set out in summer 2021 (Long Life for Art, Germany). They were used to record indoor climate at 15 min intervals, storing thermo-hygrometric measurements from different locations (Table 1) in the building as part of the project

Heritage_2020-043_Modeling-Museum [19]. Most recordings began in July 2021, with many records running to October 2022. The loggers have a temperature accuracy of ± 0.5 °C (5 °C–45 °C) with a resolution of 0.1 °C and can determine relative humidity with an accuracy of $\pm 2\%$ RH (10–90%) at 0.1% resolution. The sensors were placed around 2 m in height, although some of the loggers used additional external sensors at floor level (0 m). Absolute humidity was determined from temperature and relative humidity using the Wexler polynomial [22]. Historic data from the mammal collection came from records generated by Rotronic monitors in the storage areas and equipment from Technetics Freiburg in Saal 39. External climate data from the nearby climate station at Innere Stadt in Vienna was downloaded from Zentralanstalt für Meteorologie und Geodynamik [23].

2.3. Data Analysis and Statistics

MostraLog data was initially downloaded in the proprietary form from the climate sensors, but converted to CSV files. These were cleaned and processed using awk scripts and adopted simple linear regression analysis and other tests from online tools. Vassarstats [24] was used for the student's *t*-test and an ANOVA model, which allowed us to determine the difference between means in the climate data. The Tukey Honest Significant Difference test (HSD) was used to interpret the statistical significance of the difference in a set of means. SCILAB was used to undertake the fast Fourier transforms (FFT). Where necessary, seasonal trends in time series were removed by locally estimated scatterplot smoothing (LOESS) from WessaNet [25] and Theil-Sen slopes applied as an outlier-resistant alternative to the linear regression slope from Single Case Research [26].

3. Results and Discussion

3.1. Building Climate

3.1.1. Floors of the Building

The average climate as measured from sensors on the various floors are shown in Figure 2 as daily means that cover a period from July 2021 to September 2022, although not all records are of equal length. A few data loggers were lost during the study and replaced. The basement (FB) is typically the coldest and averages measurements from sensors in hallways, storage locations and building management sites. At times the air-conditioned attic (F4), which includes archives, offices and workspaces, is the coolest area. The exhibition halls in floor F1 and F2 are typically the warmest, well heated in winter with radiators using district heating [27], and ventilated with open windows on summer days. In some spaces, district cooling is just being installed [28]. Exhibition halls may become even hotter than the outside temperature. The differences between the floors were greatest in summer, especially that of 2022. Unsurprisingly, the basement was not only cool, but also the most humid level. In winter, most areas of the museum are very dry, as heating lowers the relative humidity, which is typically between 25 and 35% for the coldest parts of the year. It is very low in the exhibition halls from January to March (F1: $24.87 \pm 4.16\%$; F2: $25.87 \pm 3.68\%$).

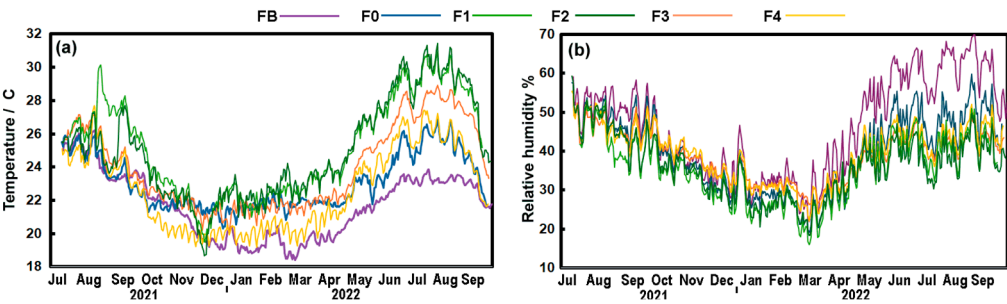


Figure 2. (a) Daily average temperature of the floors of the museum and (b) relative humidity of the floors over the period July 2021–September 2022. Note: FB: basement; F0: ground floor; F1 – F3 upper floors; F4: attic.

The average climate for a year, i.e. 365 days from 6 August 2021 to 5 August 2022 is given in Table 2 as the average temperatures from each floor, but much of the dispersion that appears in these numbers as standard deviation arises from the annual cycle. A correlated or paired ANOVA shows that the daily temperatures are not all the same. A Tukey difference test (HSD) suggested all the temperature pairs of floors were significantly different from each other ($p<0.01$). A similar analysis for relative humidity suggests again the daily values are not all the same, but in this case the Tukey HSD test suggests that some of the pairs of relative humidity measurements, notably the exhibition rooms (F1 and F3), do not differ significantly ($p>0.05$) from the ground floor (F0).

Table 2. This average climate from the various floors for a year from 6 August 2021 to 5 August 2022. FB: basement; F0: ground floor; F1 – F3 upper floors; F4: attic.

Floor	Temperature °C	Relative Humidity %
F4	22.23±2.41	38.14±6.77
F3	24.50±2.30	37.91±6.07
F2	23.44±2.84	34.53±7.36
F1	24.76±2.88	34.12±7.88
F0	22.70±1.48	38.03±9.42
FB	21.30±1.83	43.90±11.79

3.1.2. Areas of the Building

The climate in various parts of the building that reflect different aspects of use appear in Figure 3. It reveals that the climates of a given floor is not especially different. Figure 3a shows the average temperature from July 2021 to September 2022 in the rooms of the exhibition halls with a northerly aspect as compared to those with a southerly aspect. Over the time period there is little difference between the temperatures of these areas as shown in Figure 3b, where the regression coefficient (R^2) is 0.9992 and the slope close to unity (0.995), suggesting equivalence. Similar plots in Figure 3c and 3d, suggest a close relationship between the relative humidity of rooms with northerly and southerly aspects established because R^2 is 0.9976 and again the slope close to unity (1.0221). As with the aspect of the rooms, their use as offices and storage depots on F3 again suggests little difference in the temperature and relative humidity of these two sets of rooms (Figure 3e–h). In the basement, where temperatures are generally lower than the upper floors, the hallways are slightly cooler than the storage areas (Figures 2a and 3i). These are well correlated ($R^2 = 0.9987$) although the slope (Figure 3j) departs a little from unity (1.0434). The basement is more humid than the other floors (Figure 2b) although the hallways and the material storage areas are very similar (Figure 3k) and well correlated ($R^2 = 0.9981$), but the slope departs from unity (0.9536) as the hallways were more humid when conditions were damper.

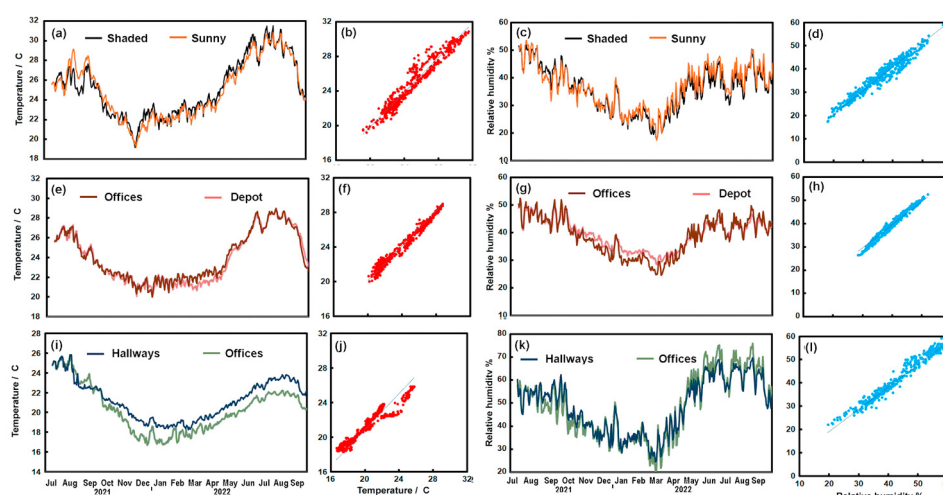


Figure 3. (a) Daily temperature from July 2021 to September 2022 on the sunny and shaded aspects of the building using the data from the exhibition rooms of F1. (b) Correlation between the daily temperature on the sunny side and that on the shaded side (c) Daily relative humidity from July 2021 to September 2022 on the sunny and shaded aspects of the building. (d) Correlation between the daily relative humidity on the sunny side and that on the shaded side. (e) Temperature in offices and storage depots on F3 (f) Correlation between the daily temperature in offices and depots (g) Daily relative humidity in offices and depots. (h) Correlation between the daily relative humidity in offices and depots. (i) Temperature in hallways and offices in the basement. (j) Correlation between the daily temperature in hallways and offices. (k) Daily relative humidity in hallways and offices. (l) Correlation between the daily relative humidity in hallways and offices.

3.2. Indoor Climate Cycles

3.2.1. Zoological Library

The climate cycles in a typical space, the Zoological Library (F3/O2 Room 508) are shown in Figure 4. The daily temperature as a function of relative humidity for the period 20 July 2021 to 10 October 2022 (Figure 4a) suggests the summer is warm ($\sim 28^\circ\text{C}$) and comparatively dry (RH 35–40%). The autumn temperatures are variable but cooler ($23\text{--}26^\circ\text{C}$). However, the winter and spring are even colder ($22\text{--}24^\circ\text{C}$) and have very dry conditions (RH 25–32%). Figure 4b shows the daily temperature and relative humidity plotted for the period 20 July 2021 to 10 October 2022. The Fourier transform of the raw temperature data collected at 15 minute intervals, in the inset, illustrates cycles at both daily and weekly frequencies, driven by activities in the museum. The summer temperatures in the library are at their lowest during the small drop just after midnight (Figure 4c). The average daily temperatures in winter are lowest at the end of the week as the library is largely unused on Saturday and Sundays (Figure 4d). There are some hints of a daily cycle to relative humidity (Figure 4c), although there is no evident weekly cycle (Figure 4d).

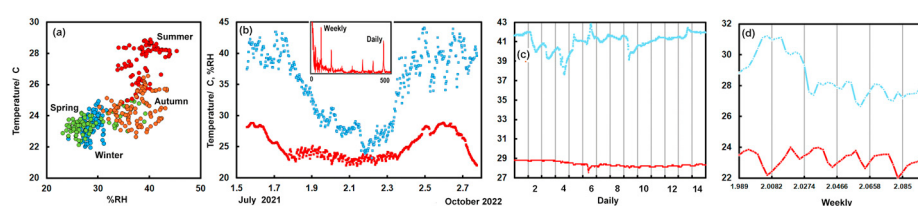


Figure 4. Climate of the Zoological Library. (a) Daily temperature as a function of relative humidity. (b) Daily temperature and relative humidity from 20 July 2021 to 10 October 2022. Inset shows a Fourier analysis of 15-minute temperature values that reveals peaks in spectral power at a given

number of cycles in the 463-day record, indicating clear weekly and daily frequencies. Note. Year as a decimal from 2020. (c) Two weeks of 15-minute temperature and relative humidity from 1-14 August 2022, grey lines denote midnight. (d) Six weeks of daily temperature and relative humidity from Monday 27 December 2021 to Sunday 6 February 2022, grey lines denote the beginning of Monday of each week. Note: Year as a decimal from 2020.

3.2.2. Diurnal Patterns in the Exhibition Halls

Figure 5a shows the diurnal pattern of hourly averages for the warm and cold seasons. Unsurprisingly the temperatures are cooler in the winter, although during the day they reveal a 4 °C increase, consistent with the galleries being warmed for visitor comfort. While the daily range of average temperatures on the floor are close to 2 °C the room temperatures are probably rather high for human comfort in summer, so the windows are typically open encouraging a breeze to enter the room. In contrast, the humidity is lower during the day when the museum is open (Figure 5b). This seems to arise through the rooms being heated perhaps by solar gain in the warm season, but by the heating system in the winter. Relative humidity levels are remarkably low in the winter and represent an environment that is likely to be too dry for some of the objects (e.g. organic materials such as paper, leather etc), although many of the smaller items within the collection are presented within cases. Most of the objects in the museum have been on display for over a hundred years, without obvious damage, even to stuffed animals. Minerals and fossils both on open display and in showcases also show no sign of damage. Nevertheless a few sensitive objects are displayed in showcases with some climate control to the interiors.

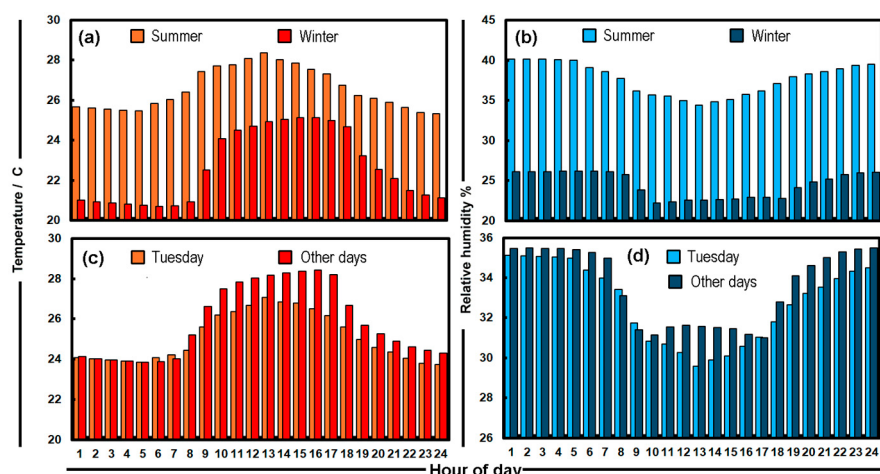


Figure 5. Hourly average climate in the exhibition halls of the F1. (a) Daily temperature cycle in warm season and cold season (b) Daily relative humidity cycle in warm season and cold season (c) Daily temperature cycle on Tuesdays and other days of the week (d) Daily relative humidity cycle on Tuesdays (museum is closed) and other days of the week.

The museum is closed to the public on Tuesdays, so we are able to examine the effect of accommodating visitor needs by comparing the differences between Tuesday and the rest of days in the week, for both temperature and relative humidity. Figure 5c shows that during the night, there is little difference between Tuesdays (when the museum is closed) and other days. However, during the day the Floor 1 is typically warmer even on Tuesday, but the difference is greater on those days when the exhibition areas are open to the public, likely a product of the heating, solar gain and open windows. Relative humidity shows a rather similar pattern, although during the day the Floor 1 it is a little drier on Tuesday, when it is closed to the public, perhaps hinting that water is generated by the visitors.

3.3. Special Climates in the Building

The building shows some consistency between areas on a given floor (Figure 3). Nevertheless, there were rooms that were distinctive on the basis of different approaches to climate control. Figure 6 shows the climate in various parts of the attic, which house the archive, parts of the botanical collection, the botanical library and the entomology collection. The daily average temperature and relative humidity (Figure 6a) for the two library rooms (Room No. 639 and 640) and the archive workshop (Room No. 638) suggest that in summer the archive workshop could occasionally exceed 30 °C, where the average for July and August 2022 was 28.14 ± 1.07 °C and in the library (Room No. 640) just a little cooler at 27.03 ± 0.83 °C; a significant difference (t -test $p_2 < 0.0001$). Temperatures are high because there is no mechanical cooling in these rooms. Winter temperatures are maintained close to 20 °C, with an average for December and January of 20.12 ± 0.63 °C and in the library just a little warmer at 21.18 ± 0.48 °C. The relative humidity was 40–50% in the summer months and lower in winter at 25–40% (because of heating).

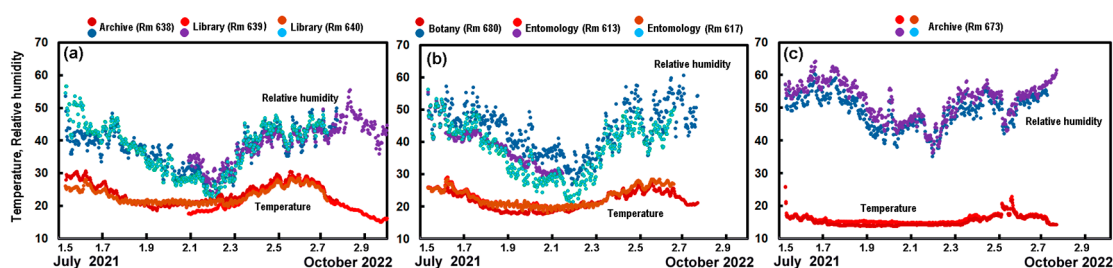


Figure 6. Daily temperature and relative humidity in (a) the library and archive, (b) collection store rooms and (c) the climate controlled archive. Note. Year as a decimal from 2020.

The storerooms for botanical and entomological collections (Rooms No. 680, 613 and 617) have somewhat more moderate July–August temperatures at 26.07 ± 1.38 °C and cooler for the period December–January 19.52 ± 1.14 °C (Figure 6b) compared with the library. Conditions were slightly more humid in the summer, with relative humidity in the low 60% range, although this is not elevated enough to be particularly damaging to most materials. The situation in the climate controlled archive areas, where there were two sensors, showed more stable temperatures. At one position in the archive from September through till the end of April, the temperature was 15.07 ± 0.23 °C, accounting for the almost flat lines in Figure 6c. Relative humidity was more variable, although it remained mostly above 40%, and stayed within the bounds 41.0–58.5% RH for 90% of the time across the entire record from both sensors.

Figure 7a shows the daily average temperature at various locations in the dome. The three sites with almost identical conditions are within the rotunda, the part of the building beneath the dome. The winter temperatures in the large room, just under the dome roof (see Figure 1) are low and distinct from the three in the rotunda, including the restaurant and the entrance to the roof hatch. The summer temperatures also get high in the room just under the dome; a few degrees greater than elsewhere in the rotunda, but this only occurs for a few days in the room under the dome. Very low temperatures in winter cause the relative humidity to be very high there. However, these extremes in both temperature and relative humidity in the dome room do not affect the collection, as items are neither displayed nor stored in this space. The dome is used in the summer months for natural ventilation with a few small windows opened so there is a constant airflow going up and out of the building. The dome is not well sealed and insulated, so its climate is strongly influenced by the outside weather. In winter, these dome windows are closed to prevent large amounts of heat from escaping the building.

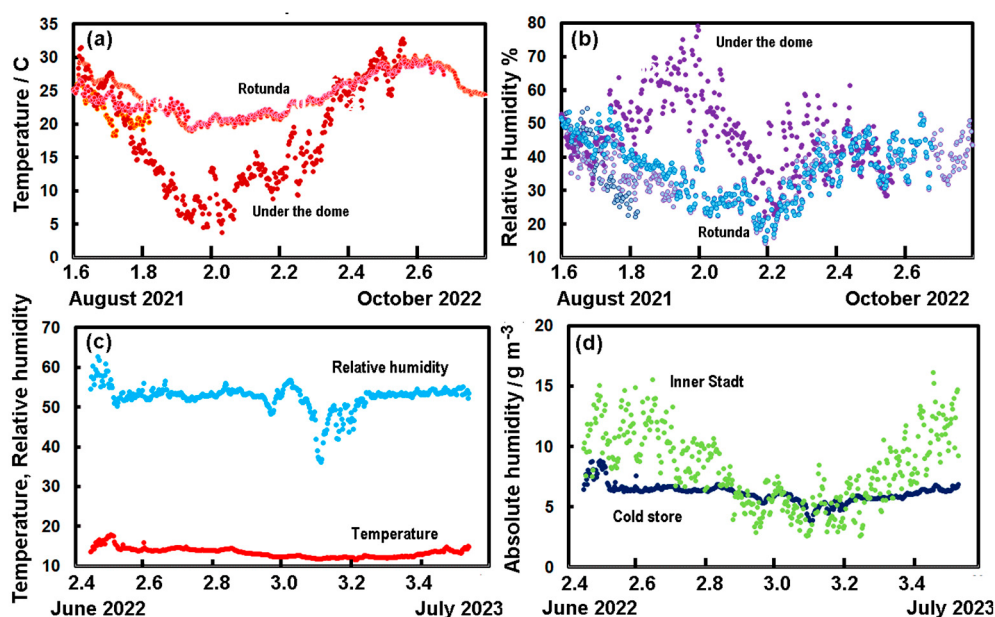


Figure 7. (a) Daily temperatures in the dome. (b) Daily relative humidity in the dome. (c) Daily temperature and relative humidity in the cold store and (d) Daily absolute humidity in the cold store compared with the external absolute humidity at Innere Stadt. Note: Year as a decimal from 2020. .

Conditions in the underground cold storage area are shown for both temperature relative humidity in the Figure 7c, although over a slightly different time period (mid 2022 – mid 2023). The temperature remains much of the time close to the 10 °C set point at 13.25 ± 1.06 °C. Relative humidity is also stable over long periods of a week or several weeks, with excursions of 10% or so. One of the problems with the cold store is that maintaining a low relative humidity requires large amounts of water to be removed from incoming air. Additional dehumidifiers run all summer and about 100 L of water is manually removed every week from the area containing the mammal collection (461.37 m²; room height: 2.71 m). The absolute humidity (as g[H₂O] m⁻³) in the cold store is shown in Figure 7d along with the absolute humidity, measured nearby at Innere Stadt illustrates the large amount of water that needs to be removed from external air to keep it dry in the cool stores.

3.4. Floor Level Microclimate

It seemed possible that the microclimate at floor level might have a different climate to that of the room at 2 m height. This could potentially be important where the floor acts as a habitat for a range of insect pests. Figure 8 shows that there is a close relationship between the temperature at the floor and that at ~2 m elevation on Floor F2. It suggests that the floor, as a potential microclimate for insects, does not appear very different from that of the air in the room in general. The best fit slope of temperature, when constrained to pass through an origin of zero, is close to unity (Figure 8a: slope=0.9949, $R^2=0.9998$). Relative humidity appears a little more scattered, though the slope is close to unity (Figure 8b: slope=0.9866, $R^2=0.9989$). The apparent scatter is much reduced when plotted as absolute humidity (Figure 8c: 0.98, $R^2=0.9993$), suggesting that the scatter is generated by temperature changes. Similar measurements at floor level were also available from F2 and F4 and showed rather parallel results.

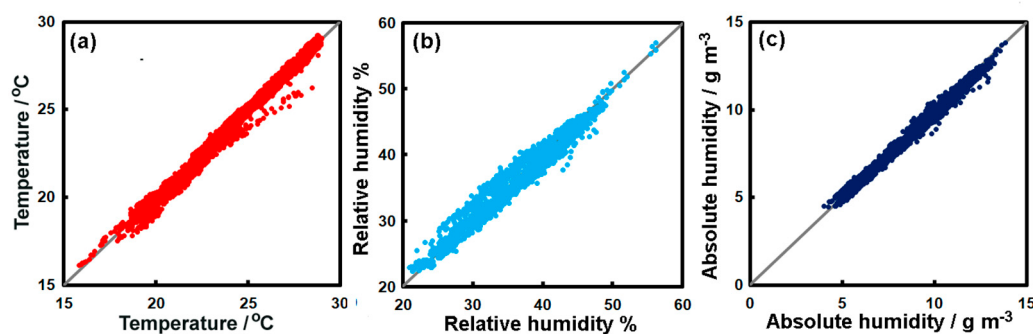


Figure 8. (a) Daily temperature at floor level as a function of that at 2 m on Floor 3. (b) Daily relative humidity at floor level as a function of that at 2 m. (c) Daily absolute humidity at floor level as a function of that at 2 m. Note the grey diagonal lines mark the line of equivalence.

3.5. Long Term Change

We had access to a decade-long record from a program that began 20 years ago, which examined climate in the underground storage area for the mammal collection (Figure 9a) and the Hall of Primates Saal 39, exhibiting prosimians, monkeys and apes (Figure 9b). This data allows some assessment of the impact of long-term change on the building climate.



Figure 9. Mammal collection in the (a) underground storage area and (b) in Saal 39, the Hall of Primates (Photographs: Naturhistorisches Museum Wien © 2024).

3.5.1. Long Term Change in the Cold Store

The temperature record (Figure 10a) shows in the decade from 2004 that the temperature, although remaining close to 10 °C rose slowly at about two tenths of a degree for each year (Theil-Sen slope $0.19\text{ }^{\circ}\text{C a}^{-1}$; $p < 0.0001$), appearing as a thick red line from multiple daily values. The early decade had an average temperature $11.23 \pm 0.88\text{ }^{\circ}\text{C}$ and can be compared with an average temperature measured in this project (2022–2023) that is slightly higher at $13.41 \pm 1.20\text{ }^{\circ}\text{C}$. This also appears in Figure 10a as a thick red line. The mammal collection is meant to be maintained at 10 °C, but in a warming world the current system appears to be struggling; in the early decade the maximum daily value reached 16.1 °C, while in the recent study period it was 17.9 °C.

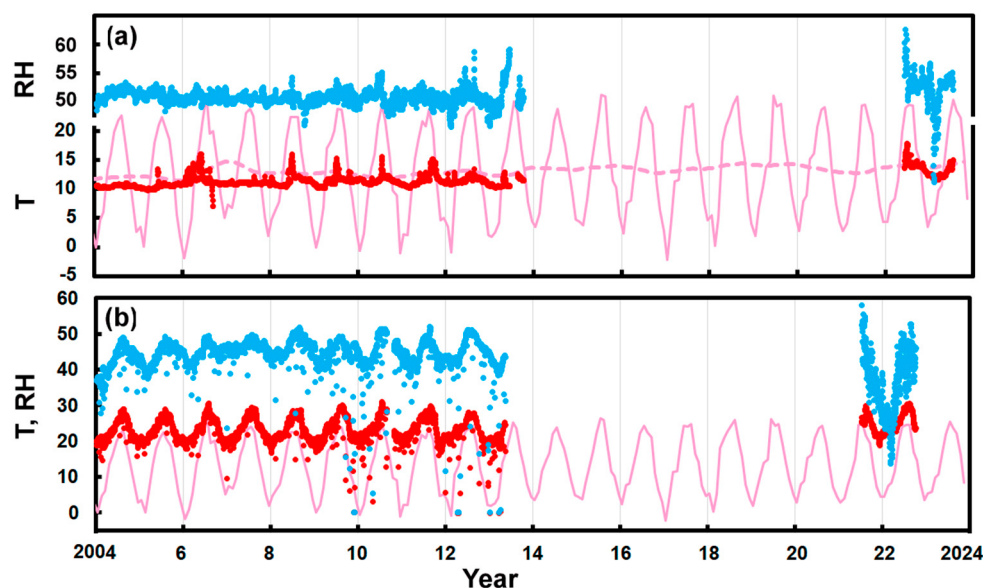


Figure 10. (a) Climate 2004–2024 in the underground mammal storage (a) temperature, thick line made of red dots), relative humidity (blue dots - note 25 scale jump), monthly temperatures as Innere Stadt (pink line) and LOESS temperature trend line (thick pink dashed line). (b) Climate 2004–2024 in the Hall of Primates – Saal 39, with temperature as a thick line made of red dots), relative humidity (blue dots) and monthly temperatures as Innere Stadt (pink line).

The monthly temperature at the Innere Stadt meteorological station, is shown as the pink line in Figure 10a. It is just a kilometre from the Natural History Museum, so is likely to be a good representation of external conditions there. Understandably the mechanically controlled climate of the mammal store is far less variable than that outdoors, but indoors we see a summer peak, even though the winter low is absent in the interior of the storeroom. The trend in external temperature over time is shown as a thick dotted line, which has the seasonal cycle removed by LOESS decomposition. The Theil-Sen slope for this change suggests an average rate of increase in outdoor temperature of $0.13\text{ }^{\circ}\text{C a}^{-1}$, whereas in the storeroom the change is probably almost double this amount. Again this may hint at the increasing difficulty the system has in maintaining $10\text{ }^{\circ}\text{C}$ in warmer summers. In the summer technical failures of the HVAC system occur regularly, which always results in a temporary increase and fluctuation in temperature.

Relative humidity in the storeroom appears to be fairly stable over time, and the Theil-Sen slope is actually negative, but statistically non-significant ($-0.33\text{ \% a}^{-1}$; $p \sim 0.2$). Although contemporary measurements of relative humidity 52.5 ± 3.4 are higher than in the past (i.e., 50.8 ± 1.2) the large variation makes any comparison difficult. However, the variation may also hint at the difficulties in maintaining a stable relative humidity through the year with the current system under a contemporary climate.

3.5.1. Long Term Change in the Hall of Primates

Figure 10b shows the climate in the Hall of Primates, which is understandably warmer and more variable than that of the store. In the earlier records, the winter temperatures are largely comfortable at $20\text{ }^{\circ}\text{C}$, although on some individual days the room became quite cold. The average temperature over the decade was $22.94 \pm 3.53\text{ }^{\circ}\text{C}$, which can be compared with that in more recent years (2021–2022) of $24.97 \pm 2.78\text{ }^{\circ}\text{C}$, an increase of almost $2\text{ }^{\circ}\text{C}$. Part of which is likely to be associated with a warming climate. The relative humidity is variable compared with the store with occasional very low values ($<20\%$), that were especially persistent in the winter of 2021/2.

3.6. Managing the Museum Climate

The museum has, at times, an extreme indoor climate: very hot in the summer and dry in the winter. This is a result of (i) a lack of cooling or humidity control in most of the larger rooms, (ii) past unregulated heating in winter (sometimes spaces become overheated, so windows are opened), (iii) large windows to all sides of the building that can admit sunlight, (iv) ventilation all year with open windows in most of the exhibition rooms and (v) many visitors arriving throughout the year. The years 2022 and 2023 both had over 800 000 visitors per year, although in 2021 only 400 000 because of a closure that resulted from COVID-19 restrictions. Heat is trapped in the museum, with very large windows facing west and south, so even with ventilation through the open windows the inside temperature is equal or even higher than the outside temperature. This can make some of the exhibition spaces uncomfortably hot in summer. Overheating has become a concern for heritage buildings under a warming climate [29].

The attic had been expanded during renovation to contain offices, libraries and store rooms, but the roof is not well insulated (only 15 cm thick), so it can get very hot in the summer months. However, this cannot be changed with better insulation and adding more rooms to the HVAC system are not possible for architectural reasons. A few rooms such as the archive are air-conditioned and have a cooler and stable climate, which is important for the sensitive objects housed here (paper, paintings). The original building had a passive cooling system, but it is not in use any more. Due to building adaptations, modernisation and fire prevention, the large openings to the outside of the building connecting to the basement and the vertical shafts (*Luftbrunnen*) that transported cooled air from the basement to all floors were permanently sealed after the World War 2. They can no longer revert to their original use, although some other historic buildings in Vienna (Hofburg Imperial Palace; see [30] for a detailed description), built at the same time, still use their passive cooling systems. The dome of the building allows some climate control options in the summer by removing hot air. In winter temperatures in the space above the dome can drop to 5 °C.

A range of new ways to manage the heating and cooling of the building have been explored as energy efficiency has become increasingly important given environmental concerns along with increasing energy costs. In recent years this has meant more stringent regulation of climate than in previous winters (heating in winter 2021/22 was limited to 19 °C). Such control can involve the removal of large amounts of water from the incoming air in the storage areas in the summer. The museum is currently able to take advantage of Vienna district heating that supplies warm water to the building radiators. District cooling was also installed in 2024 and the museum is now making use of this to partially cool some areas. Some of the large windows are now shielded by outdoor shades which is also projected to lower the room temperature by 2 °C. This had already been successfully installed in the main building of the Kunsthistorische Museum (a very similar building opposite of the Natural History Museum) and in the rooms of the Sammlung Alter Musikinstrumente, Weltmuseum and Hofjagd und Rüstkammer, all belonging also the Kunsthistorische Museum.

4. Conclusions

The Natural History Museum in Vienna has an indoor climate with low relative humidity in winter, and high internal temperatures in some parts of the building in the summer. The historic cooling and passive ventilation is not in use any more so the museum now needs to be adapted to hotter weather likely to come as a result of climate change. This means the district cooling systems and the use of shades may become increasingly important. Milder winters could lessen the amount of heating required, so low humidity in future should not be so much in evidence. Our future work will undertake comparisons across Lower Austria where there are a range of different external climates, yet similar large historic buildings that house important collections. It will also be useful to explore the effectiveness of newer methods that aim to improve indoor climate.

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