

Environmental Monitoring at the Rotunda

Technical Note · method, standards, instrumentation and calibration · September 2026

This note records the method behind the environmental monitoring of the Rotunda and accompanies the record published at rotundatrust.org.uk. It is a working document of the Rotunda Trust: positions, calibration values and derived quantities are stated as at the date above.



The Rotunda from the south: the lead tent roof rising to the central lantern. Photograph Chmee2, via Wikimedia Commons, CC BY-SA 3.0.

1. What is at stake in the timber

The roof structure is of timber and iron, built when the building was re-erected on Woolwich Common in 1820 and repaired at intervals since. Timber is hygroscopic: its moisture content tends toward equilibrium with the relative humidity of the surrounding air, and it changes dimension as that moisture content changes, principally across the grain. At 50% relative humidity softwood equilibrates near 9 to 10% moisture content; at 65%, near 12%.

The damage regimes sit at the extremes. Surface humidities sustained above about 80% permit mould germination, and moisture contents above roughly 20% admit decay fungi. At the dry extreme, timber shrinks, checks along the grain and works loose at joints and iron fastenings, the iron responding to temperature and the timber to moisture, by different amounts and to a different rhythm. Between those extremes aged timber tolerates the level it has reached but is sensitive to the rate of change: each humidity cycle imposes a cycle of strain, and repeated cycling accumulates fatigue at the connections and laminations that a steady state does not.

Massive construction moderates this. The brickwork and roof timbers act as a hygric buffer, taking up and giving back moisture themselves, while the thermal mass delays and attenuates the external temperature wave. Both effects are measured in the record: external swings exceeding 20

percentage points of humidity are attenuated to under 4 within the drum, and the interior temperature wave lags the exterior by several hours at a fraction of its amplitude.

2. What the monitoring is for

The purpose is to establish from measurement the conditions in which the building deteriorates least. The method follows BS EN 15757:2010, which derives target conditions from a building's own historic climate, characterised by a 30-day central moving average and the variability about it, rather than from an imported setpoint. That requires at least a full measured year, so no target band is shown in advance of one.

Relative humidity. No interior band is adopted. What matters is stability at a defensible level and a limited rate of departure from it, not a particular number. Pending the measured year the published charts mark only the mould germination zone above 80%. The dry extreme is not marked, no comparable threshold being statable in advance, but the record to date lies closer to it than to the wet one: readings in the upper roof volume reached 31% relative humidity and an inferred moisture content near 6% in the first fortnight of August 2026.

One qualification attaches to that derivation. The building was heated through most of its working life, a purpose-built boiler house of the 1860s having served successive systems, the last removed after the museum's departure. It has been unheated, unoccupied and largely unventilated since, the windows being fixed or painted shut. The measured year therefore characterises the regime of roughly a generation, not the conditions under which the fabric spent the preceding century and a half.

Temperature as a free variable. Moisture content in timber is governed by relative humidity rather than temperature, so interior temperature can be allowed to float within limits set by the condensation margin at the coldest surfaces, by the rate of change, and, under occupancy, by comfort and licensing. This permits humidity to be governed without heating to a fixed temperature, which is both less interventionist and materially less energy-intensive.

Air under occupancy. Each person adds of the order of 100 W and 100 to 150 g of water an hour. With the present fixed openings a substantial gathering would raise vapour and carbon dioxide concentrations well before it became thermally uncomfortable. Carbon dioxide is adopted as the measure, with a working objective below 1,000 ppm, and sensing would be added before any regular occupation so that ventilation is sized from measurement.

Means. These objectives are stated independently of how they might be met. The building is in the ownership of the Ministry of Defence, and any physical intervention would be a matter for the owner, for listed building consent and for consultation with Historic England, the local planning authority and the Trust's conservation advisers. Nothing is proposed here. The purpose of the record is to allow options to be compared on measured evidence, and any regime to be verified after the fact rather than assumed.

3. Instruments and positions

Eight multi-sensor units (Dragino LHT65S-E3) measure air temperature, relative humidity and, by external probe, the temperature of a fabric surface. One weather station (SenseCAP S2120) records external conditions. All report at five-minute intervals over a low-power radio network to a gateway on site, and are logged continuously to an append-only record.

Vertical profile. Sensors at floor level, at a ring 5 m above floor, at walkway level, 11 m, and beside the king post, 16 m, establish the profile from the occupied volume to the upper roof. The king post position has been measured since 22 September 2026; until safe access was available its sensor was held beside the floor unit, establishing its offset against an installed reference before it was moved. The measured gradient is markedly non-linear, approximately 1.1 K per metre between 1.5 and 5 m and 0.5 K per metre between 5 and 11 m, the lower layer being held down by the cool floor slab. A single level could not have revealed this.

Horizontal distribution. The 5 m ring places sensors on the south, east, west and south-west faces, each referenced to the nearest numbered truss, distinguishing a building-wide condition from a local one. The south position is on truss 21, the member with the recorded bottom chord failure, and the walkway sensor is on the same truss, giving a vertical pair on the element of greatest structural interest. A further sensor in the annexe records the coolest part of the fabric measured to date.

Air and surface pairing. Each unit measures both the local air condition and the temperature of an adjacent solid element, because condensation risk is governed by surface temperature against the dew point of the adjacent air rather than by bulk humidity. Roof probes sit in the gap between sarking boards in contact with timber beneath the lead; the probe at the centre of the drum rests on the floor slab; one probe, in the annexe, is deliberately suspended in subfloor air and is treated as an air measurement throughout. Probes run 8 to 21 K above local air temperature on a sunny afternoon, ranked broadly by solar aspect. Fixings to historic fabric are reversible and adhesive-free, and none is made to painted or inscribed surfaces.

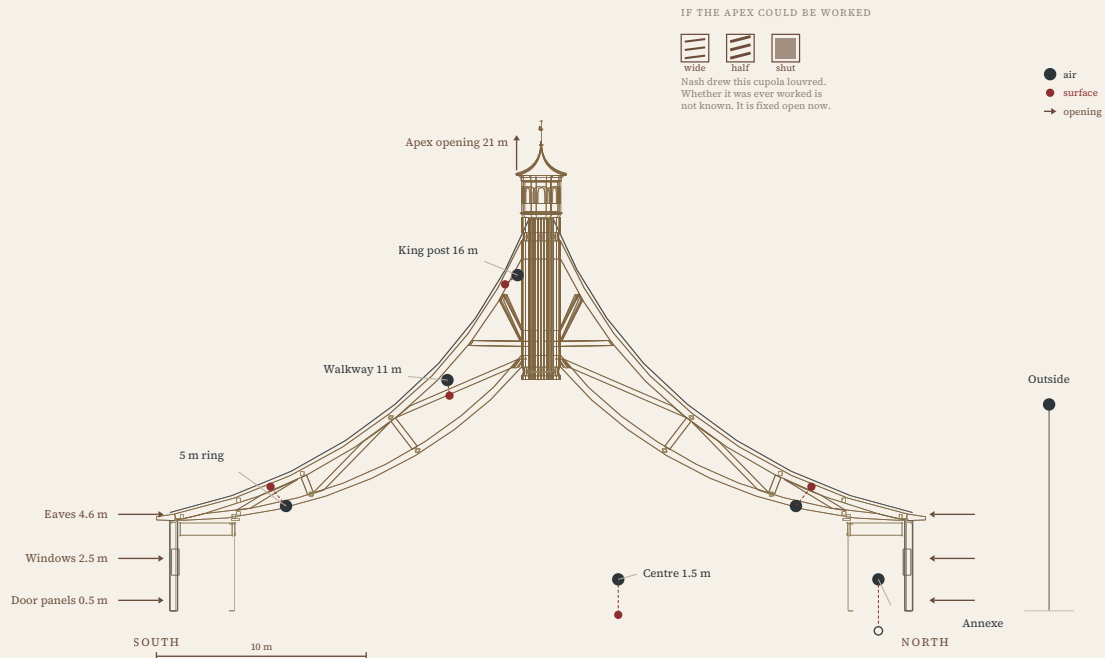
The gap between sarking boards varies from position to position, so a probe in a wider opening sits partly in roof void air and reads closer to air temperature, and contact area differs between installations. Differences between positions should be read with that in mind. Each probe's behaviour over time, and its reading against the dew point of the adjacent air, are unaffected. The contact condition of each probe is recorded at installation.

External conditions. The weather station stands on a post approximately 8 m above ground and 30 m north-west of the annexe. The building and surrounding trees disturb the airflow, so its wind reading indicates shelter rather than free-stream wind. Its rain gauge is a tipping bucket of 0.254 mm per tip reporting a lifetime cumulative total, from which rainfall is derived by increment; increments recorded between 07:00 and 10:00 UTC on 10 August 2026 arise from handling during relocation and are excluded, the raw counter being left unaltered. At 8 m the gauge sits well above the standard exposure and a systematic under-catch should be expected. Its calibration will be verified by measured pour at the next attendance.

Reference observations. Because the mast stands in the building's lee, a second stream is logged from London City Airport, 2.5 km north at a standard 10 m exposure: wind, temperature, dew point and pressure, half-hourly from the routine aviation reports. The airport series is taken as the free-stream wind. Over the paired record the mast reads between 0.10 and 0.21 of it depending on direction, about 0.13 overall, which is a property of the site rather than a fault in either instrument. Dew point at the two sites agrees within 0.7 K, a running check on the humidity sensing.

The ventilation circuit. Air enters low, through door panels at 0.5 m, window insets at 2.5 m and eaves holes at 4.6 m, and leaves high through the apex at 21 m, driven by the temperature difference between inside and out and by wind pressure across the openings. The apex is in suction under both, so it is the dominant outlet in either regime, and openings in series are

governed by the smallest: the head of the stack therefore commands the whole circuit. Nash's section drawing shows the cupola with louvred faces, drawn distinctly from glazing, so the opening is original design intent. Whether it was ever adjustable is not known. It is fixed open now, and every other opening in the building is fixed with it.



Section through the building showing the full array. Dark markers are the sensor bodies, reading air; smaller red markers are the external probes, reading the temperature of the fabric they rest against. The cut is north-south, so the east and west walkway positions are shown in projection. Arrows mark the ventilation openings and, under buoyancy alone, the direction of flow: in at the three low levels, out at the apex. The three small figures show the positions a louvred opening of this kind offers, which is the distinction between a building that can be worked and one that cannot.

4. Calibration and uncertainty

The instruments were co-located before installation and their offsets computed against the group mean over settled night hours. The spread is 0.47 °C in air temperature, 2.1 percentage points of relative humidity and 0.26 °C on the probes, within the manufacturer's specification, and agreement held across a range and rate of change well beyond service conditions. Propagated through the relations below, instrument uncertainty corresponds to about ± 0.5 K in derived dew point and therefore in the condensation margin: differences between positions smaller than that are not significant. Comparisons are most reliable in settled conditions, the housings differing in thermal response during rapid change. Offsets are applied in analysis, not to the published series. The instrument-by-instrument record is held by the Trust and available on request.

5. Derived quantities

Each unit reports air temperature T , relative humidity RH and a surface temperature T_s .

Everything else is derived. Saturation vapour pressure uses the Magnus form with the coefficients of Sonntag; vapour concentration follows from the ideal gas relation; dew point is obtained by inverting the same relation; and the condensation margin is the surface temperature against the dew point of the air measured at the same sensor.

$$e_s(T) = 6.112 \cdot \exp[17.62T / (243.12 + T)] \quad \text{hPa}$$

$$AH = 216.7 \cdot e_s(T) \cdot RH / 100 / (273.15 + T) \quad \text{g m}^{-3}$$

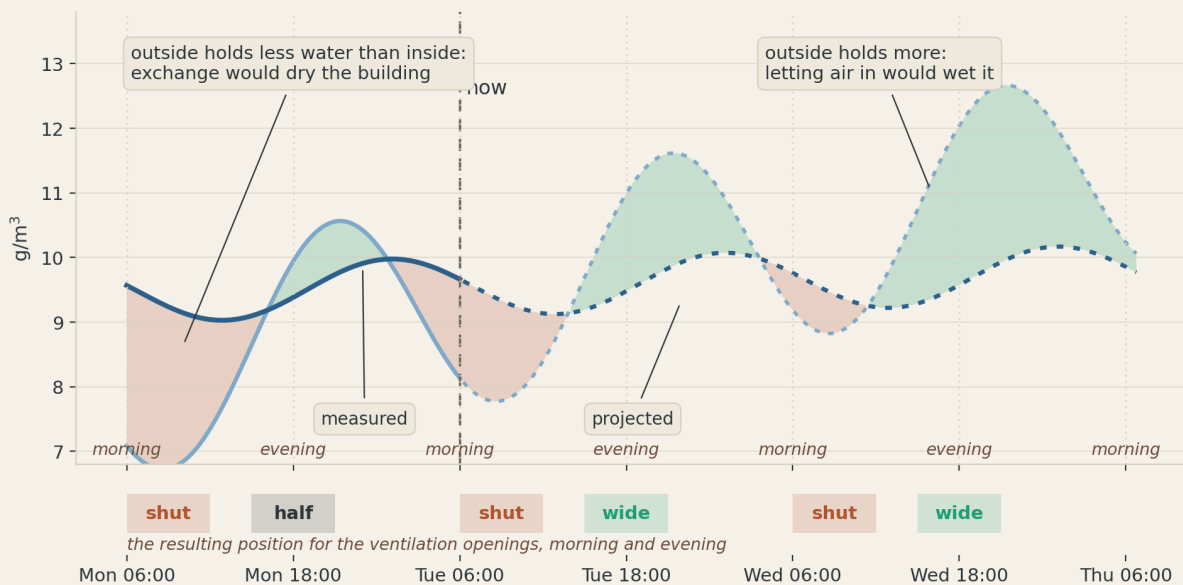
$$\gamma = \ln(RH / 100) + 17.62T / (243.12 + T), \quad T_d = 243.12\gamma / (17.62 - \gamma) \quad ^\circ\text{C}$$

$$\Delta T_{\text{cond}} = T_s - T_d(T, RH) \quad \text{K}$$

A margin of zero means the surface is at the dew point of the adjacent air and will begin to wet. Because humidity at a surface rises as that surface cools, mould thresholds are reached before the margin reaches zero, so a positive margin alone is not a sufficient criterion over sustained periods.

The humidifying and drying potentials on the moisture chart are the sign of the difference in vapour concentration between exterior and interior, evaluated on a common time base. The quantity describes the direction in which any exchange of air would move the interior, not whether such an exchange would be desirable, which depends on the interior condition relative to the damage regimes above. Rainfall is the depth fallen in the hour to each reading on the short views and the calendar day total on the long one, the tip increment setting the resolution. Seasonal trend is the 30-day central moving average of the daily mean, in accordance with EN 15757, computed only where the record spans 30 days.

6. Reading the record



Reading the charts, using vapour concentration as the example, on a made-up week in which a dry airmass gives way to a wet one. Solid lines are measurement and broken lines are not: ahead of the present moment they are projection or forecast. The vertical rule marks now; the faint verticals divide the day at 06:00 and 18:00. Green marks the periods when the outside air holds more water than the inside, russet the periods when it holds less. The strip beneath draws the consequence for the ventilation openings, twice a day. With the openings fixed as they are it is hypothetical, and it is the reason the difference between the two lines is worth measuring at all. The same conventions apply to the other charts.

The record is published at four fixed views rather than a continuous zoom, because the useful quantity changes with the period considered and one adjustable timescale would answer every question badly. **Outlook** shows the past day and the following two at half-hourly intervals: the operational view, its horizon set by the forecast's useful skill. **Past two days** shows every reading at five-minute resolution: the diagnostic view, fine enough to show an opening, an intervention or

the passage of a front, and long enough to set one night beside the last. **Past week** shows seven days at fifteen-minute intervals, the view at which the diurnal cycle, the attenuation of the external swing and the phase lags are all legible at once. **The record** shows the complete series reduced to one shape per day, the daily mean with a band spanning that day's extremes, which preserves trend and amplitude while remaining legible over years.

Derived quantities are presented alongside the measured ones at every view, because vapour concentration and the condensation margin carry the conservation meaning, while relative humidity alone is temperature-dependent and misleads when compared between locations at different temperatures.

7. Forecast and projection

External conditions are taken from the Norwegian Meteorological Institute's Locationforecast service, retrieved every six hours and held in the record. Interior conditions are projected from the building's own measured response to those conditions. Each interior state variable S is treated as a first-order lag on an external driver D , with additional driving terms X :

$$dS/dt = k(D - S) + \sum b_i X_i + c$$

Couplings are fitted by least squares from the trailing seven days on the floor series, the longest continuous record, and refitted on every page load. Interior temperature is driven by external temperature and carries a lagged solar term, sunlight otherwise being absorbed into the constant and lost as the projection rolls forward. Fabric temperature carries a further term for radiative loss to a clear night sky, cloud being taken from the reference station behind the present moment and from the forecast ahead of it. Interior humidity is carried as the slow variable, drawn toward the level the exterior's daily-mean vapour would set at the interior temperature, with vapour concentration derived from it, so that the diurnal swing follows temperature as the building does. The floor projection is carried to each level by that level's stratification, fitted on that level's own record, the king post included once its record is three days long.

The solar lag is not chosen by ordinary fit. Candidate lags are each fitted and rolled forward a day across the record, and the one whose day-ahead position lands closest is kept. The two criteria disagree materially: the residual fit prefers a lag of about an hour, which tracks each reading well and drifts over a day, while the day-ahead test selects a lag near twelve hours, of the order of the roof covering's own conduction time. A projection is read a day or two ahead, so it is fitted on that horizon.

Verification. Archived forecasts for 30 July to 9 August 2026 were compared against the external station over 194 overlapping hours. Forecast air temperature showed a bias of +0.48 K and a mean absolute error of 1.86 K; forecast humidity a bias of -5.0 percentage points and an error of 6.0 points. The temperature figures are adequate to drive a two-day projection; the humidity figures are weaker and biased dry, which matters because the sign of the moisture difference governs the interpretation of the vapour chart. Part of the apparent difference is exposure rather than error: against the airport reference the station reads about a quarter of a degree warm at midday and over a degree cool at night, as a mast over grass should against a dockside airfield. Forecast wind is verified against the airport, both being standard-exposure quantities.

Measured drivers. Regression of the record ranks the external influences. Interior relative humidity is governed first by the moisture content of the outside air, which alone carries about two thirds of its variance, then by external temperature acting through the interior's slow thermal response. Interior vapour shows two channels of comparable size: exchange with outside air at no appreciable lag, and release from the fabric following sunshine by about six hours. Sunlight

warms the outside air within an hour or two, narrowing the interior's excess at the lower levels, and conducts through the roof covering over many hours, raising the top. Wind to free-stream speeds near 10 m/s explains under one per cent of any interior quantity; the exchange rate awaits direct measurement by tracer test.

Limitations. The model represents the building in its present, fixed ventilation state; any change to the openings invalidates the fitted couplings until refitted. The stratification between levels is fitted on a narrower range of solar lags than the roof appears to hold, so the levels above the floor, and the king post with the shortest record among them, are the least well constrained parts of the projection. The projection assumes no occupancy and no intervention: it describes what the building will do if left alone, and is indicative.

8. Sources

Physics and material behaviour. T. Padfield, *The Role of Absorbent Building Materials in Moderating Changes of Relative Humidity* (PhD thesis, Technical University of Denmark, 1998), and the essays at conservationphysics.org · D. Camuffo, *Microclimate for Cultural Heritage*, 3rd edn (Elsevier, 2019) · M. F. Mecklenburg, C. S. Tumosa and D. Erhardt, on the mechanical response of wood to humidity change (Smithsonian Museum Conservation Institute) · L. Bratasz and R. Kozlowski, on allowable microclimatic variations for painted and structural wood, *Studies in Conservation* · K. Sedlbauer, on mould growth prediction and isopleth methods (Fraunhofer IBP, 2001).

Standards and measurement practice. BS EN 15757:2010, *Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials* · BS EN 15758:2010, *Procedures and instruments for measuring temperatures of the air and the surfaces of objects* · BS EN 16242:2012, *Procedures and instruments for measuring humidity in the air and moisture exchanges between air and cultural property* · BS EN 15759-1:2011, *Indoor climate: guidelines for heating churches, chapels and other places of worship* · PAS 198:2012, *Specification for managing environmental conditions for cultural collections* · Building Device Naming Standard (BDNS).

Building practice. Historic England, *Practical Building Conservation: Building Environment* (Ashgate) and guidance on energy efficiency and environmental management in historic buildings · CIBSE Guide A, *Environmental Design*, on thermal mass, decrement factor and time lag.

On the building. E. Cole, S. Newsome and V. McCaig, *The Woolwich Rotunda: From Waltzes to Wargames* (Liverpool University Press / Historic England, 2025) · J. Clarke, "Cones, Not Domes", *Construction History* 21 (2005).

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