

IBP-Report HTB-005/2016

PSPP First Climate Measurement Campaign at the Necropolis of Porta Nocera

On behalf of

PSPP

Pompeii Sustainable Preservation Project

The report includes:

54 Pages Text

14 Tables


70 Figures

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1 Background and Aim of Project

The climate measurement campaign is part of the investigation of the Pompeii Sustainable Preservation Project PSPP about the damage processes at the Porta Nocera Necropolis at Pompeii. Hence, a general overview of the existing climate conditions and distribution of the local climates in the western and eastern part of the Necropolis is of particular interest. In regard to climate impacts, two different questions were analyzed:

- a) The microclimate inside a tomb chamber with severe problems of microbial growth
- b) The microclimate behind glass protections and their influence on damage processes like moisture transport, salt efflorescence and hygric or thermal stress to plasters and paint layers

The overall aim of the climate measurements was to get a greater idea about damage processes to develop tailored solutions for preventive conservation of the tombs of the Porta Nocera Necropolis that could also lead to concepts for other buildings or sites at Pompeii.

2 Climate Measurement

2.1 Concept of Measurement

The measurement at the Necropolis is mainly concentrated on three places. Figure 1 gives an overview of the site with the marked places. Additionally, the measurement concept is shown by an overview sketch in Figure 2 and by detailed sketches and pictures in Figure 3 to Figure 16. In Table 1 all sensor positions are listed with a short description of each type of sensor and position.



Figure 1:
Pompeii with part of the Necropolis. The red arrows indicate the measurement points at the tombs. (Source: google maps)

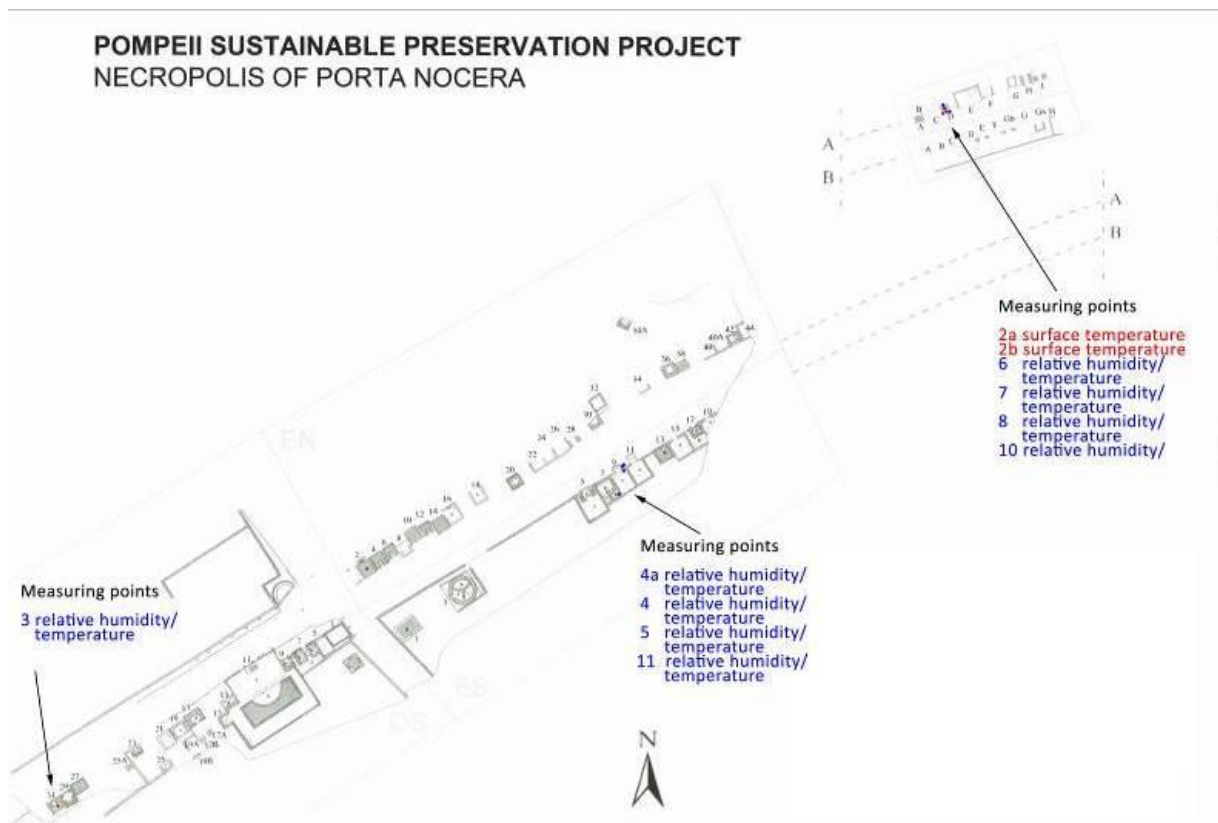


Figure 2:
Pompeii ground sketch of the Necropolis area OS (left), ES (middle) and D-N (right) with indicated measurement points at the tombs.

Area OS



Figure 3:
View from west to east at the beginning of the tombs. On the top of the first tomb the measurement of the outside climate is placed between the two lions underneath the temporary shed roof.

Area ES

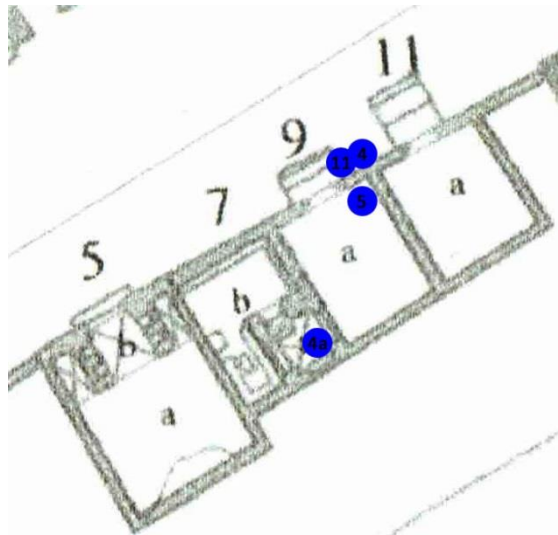
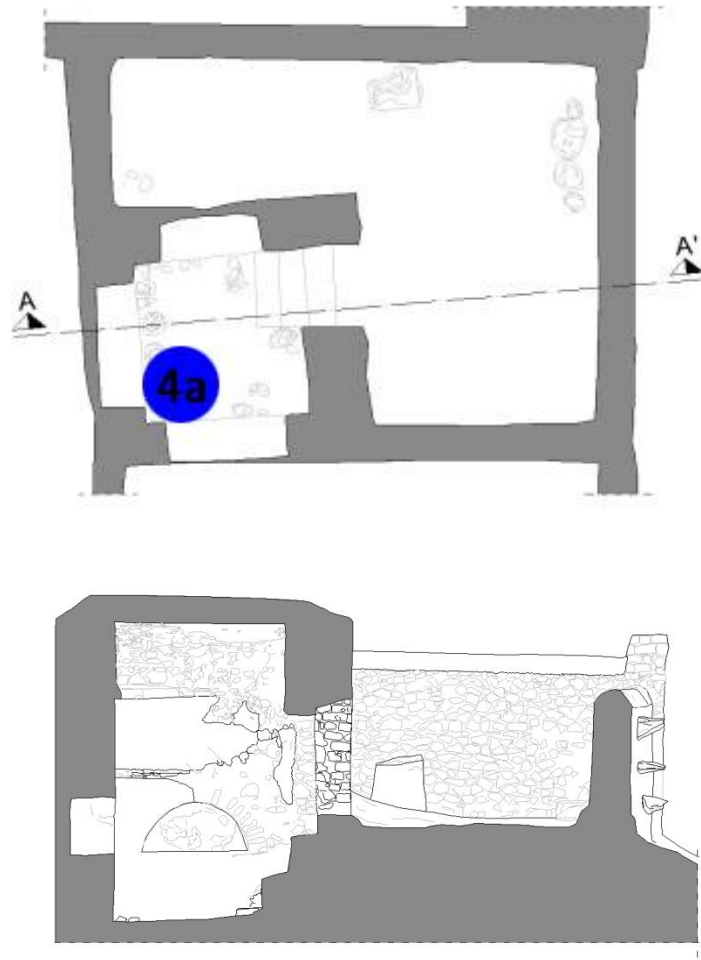


Figure 4:
Detail of the measurement concept at the area ES tomb ES7 and ES9 (compare Fig 2).



Section A-A'

Figure 5:
Detail of the measurement concept for tomb ES 7 in ground floor and cross section (Sketches: Source IBAM [2]).



Figure 6:
View from the street to the north side of tomb ES7 and ES9. The inner of the enclosure of ES7 is only accessible by the cantilever stone stairs. The front of ES 9 is protected by protective glass. Its wall roofing is supported by a scaffold.



Figure 7:
Measurement at tomb ES9 on the front to the street underneath the protective glass. The Sensor is placed on a cornice (red arrow). The right figure shows the rear side of the wall from the inside of the enclosure. The Sensor is placed underneath the wall roof (red arrow).



Figure 8:
Measurement at tomb ES7. The wall of the enclosure hides the tomb. Only the top of the tomb can be seen from the street. The right picture shows the rear view of the tomb with a protective coverage to prevent the rain from draining away into the tomb.



Figure 9:
Tomb ES7 as a 3D model with view from north-east (Source IBAM [2]).



Figure 10:
View of the interior walls of the tomb ES7 beginning left with view to the north wall, east, south and west wall. The sensor is placed on the remaining cornice in the corner east-south wall at a height of about 2.5 m (Source IBAM [2]).

Area D-N

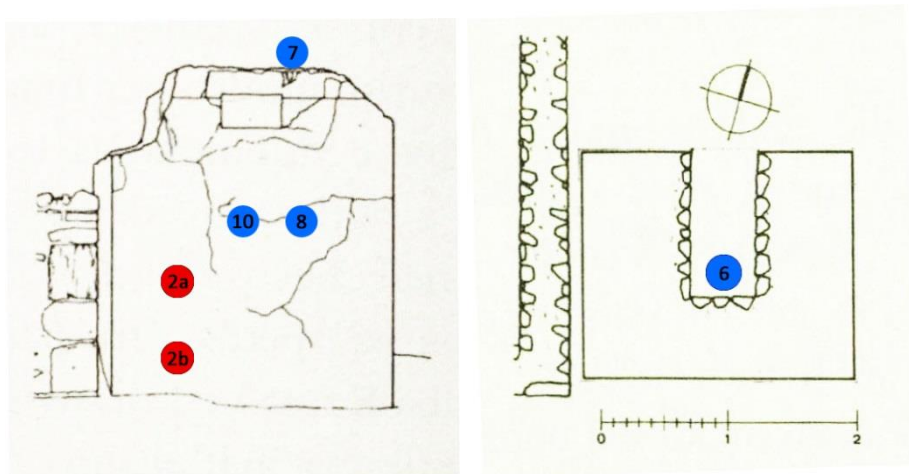


Figure 11:
Detail of the measurement concept at the area D-N tomb D-N-7. The left picture shows the measurement points at the south side of the tomb. The right picture shows the position of the data logger in the cave, accessible from the north side of the tomb (source of drawing of tomb [1]).



Figure 12:
Tomb D-N-7 with view on the south and east side with protective glass (left picture) and view on the north and west side at the right picture. The arrows show the position of the data logger No 6 and 7.



Figure 13:
Data logger inside a tin placed in a hole at the north side at Tomb D-N-7. The hole is about 0.8 m deep.

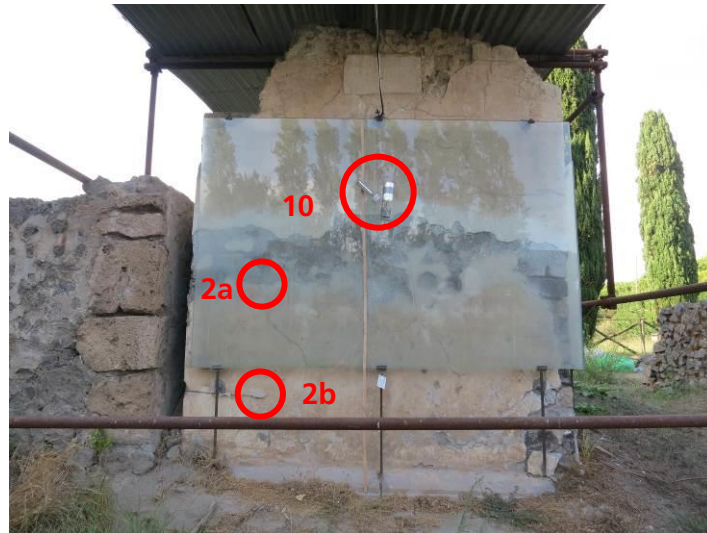


Figure 14:
Detail of the measurement concept of tomb D-N-7 on the south façade. Two surface sensors were placed on the wall, as well as a data logger for the micro-climate in the gap behind the protective glass.



Figure 15:
Carefully, reversible mounted sensor on the 2000-year-old original plaster. The upper picture shows the sensor after mounting on 14.11.2014 and the picture in the middle shows the sensor almost falling down on 08.09.2015. Therefore, the sensor was fixed again (lower picture).

The protective glass is mounted on metal poles. It is a laminated safety glass (VSG) with 8 mm thickness. The size of the glass is on the south side of about 1.4 m height by 2.1 m width. The distance to the wall is about 6 cm.



Figure 16:
Detail of the gap between original wall and protective glass. The right picture shows the temperature sensor after one year. The sensor was placed on the edge of an open plaster. After one year the sensor is “buried” by down coming sand of airborne dust and the decomposing plaster above.

Table 1:
Positions and description of used sensors.

Position	Description	Sensor
1	n.n.	
2a	tomb D-N surface behind protective glass	T_{surface}
2b	tomb D-N surface	rH, T
3	tomb ES 31 reference outside climate	rH, T
4	tomb ES 9 front I	rH, T
4a	tomb ES 7 inside	rH, T
5	tomb ES 9 back	rH, T
6	tomb D-N Tin inside	rH, T
7	tomb D-N on the top	rH, T
8	tomb D-N gap I	rH, T
9	n.n.	
10	tomb D-N gap II	rH, T
11	tomb ES 9 front II	rH, T

2.2 Results of Measurements

2.2.1 Tomb OS 31, Measuring Point 3 (reference outside climate) compared with Tomb D-N, Measuring Point 7 (outside climate)

Tomb OS 31 P3 reference outside climate

The top of the tomb OS 31 serves as reference climate, since the place is partly shaded by surrounding nature and constructions, see Figure 3.

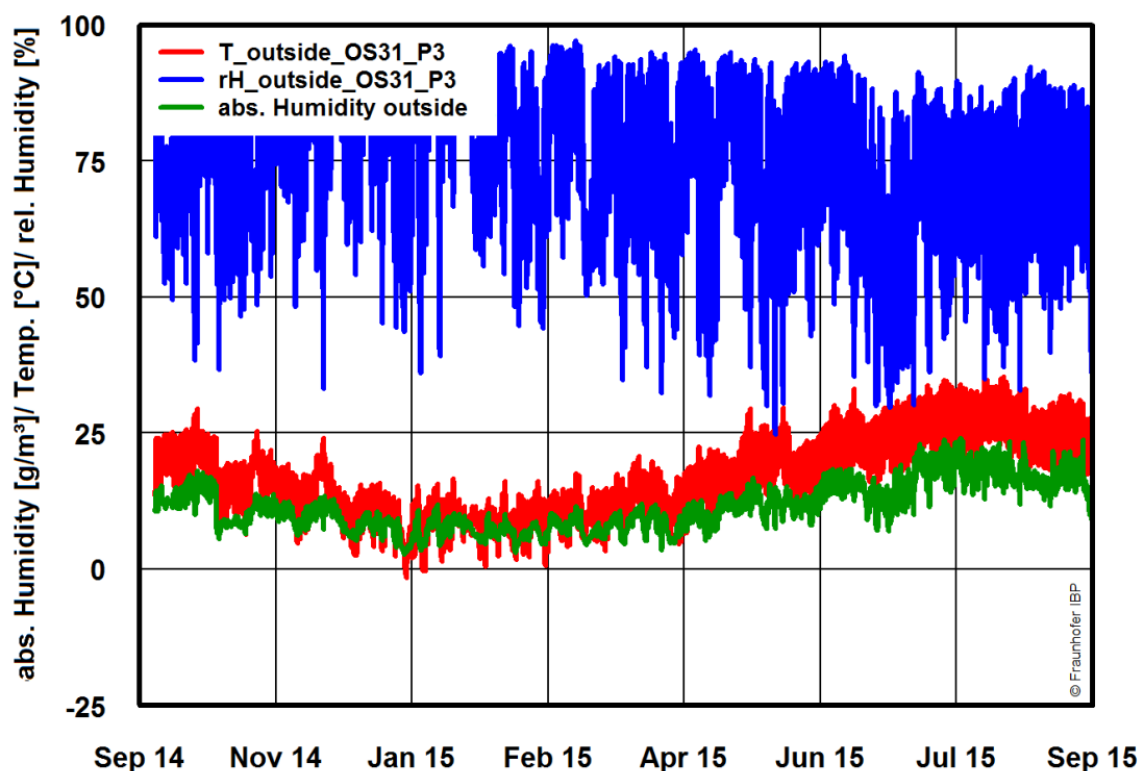


Figure 17:

Overview on the reference outside climate at tomb OS 31. The graphs show the hourly mean of 10 minutes interval measured data, from 30.09.2014 until 08.09.2015.

Table 2:

Statistic data of the reference outside climate OS 31 P3, from 30.09.2014 until 08.09.2015.

Outside Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	75.4	15.4	24.7	47.8	77.6	95.4	97.8	8227
Temperature [°C]	16.9	7.7	-1.6	5.5	16.2	30.3	35.4	8227
Absolute Humidity [g/m³]	11.3	4.4	2.7	5.3	10.6	19.4	24.1	8227

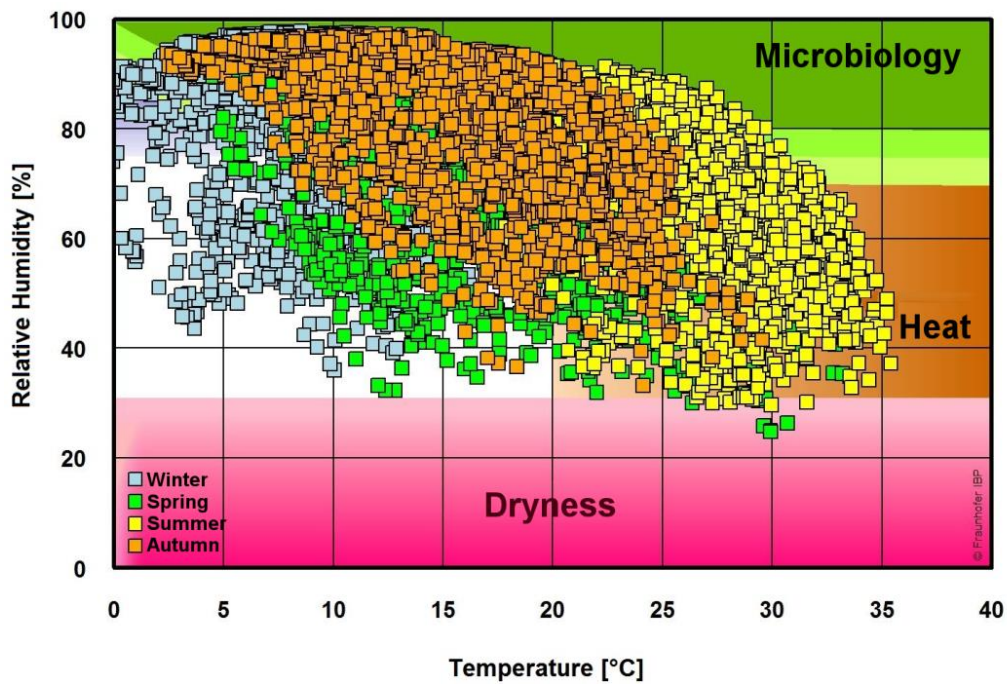


Figure 18:
Scatterplot of the reference outside climate at tomb OS 31. The graphs show the hourly mean of 10 minutes interval measured data, from 30.09.2014 until 08.09.2015.

Tomb D-N Point 7 top of tomb

The measurement on top of tomb D-N-7 P7 is in an approximately 350 m distance from the measurement at OS 31. The situation is comparable but lesser shaded by the surrounding, see Figure 12.

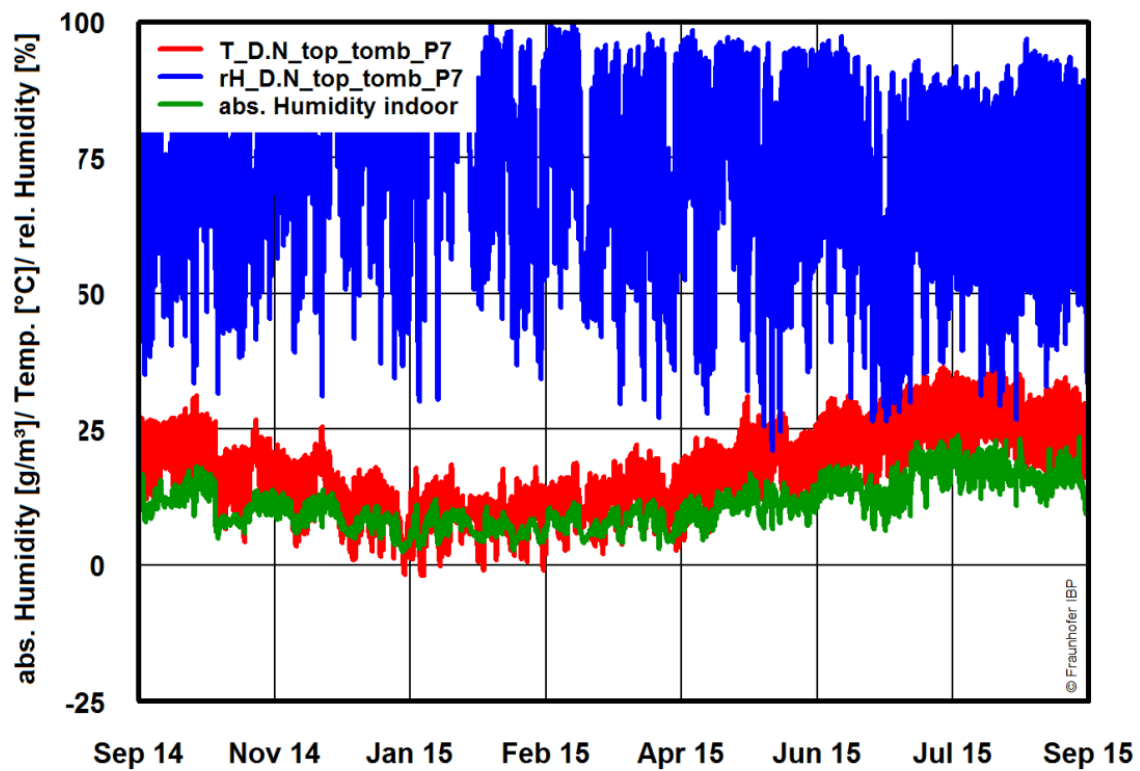


Figure 19:
Overview on the reference indoor climate at tomb OS 31. The graph shows the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Table 3:
Statistic data of the reference indoor climate OS 31 P3, from 24.09.2014 until 08.09.2015.

Indoor Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	73.0	18.4	21.1	41.7	74.7	97.4	100.0	8379
Temperature [°C]	17.2	8.0	-2.0	5.0	16.6	31.2	37.7	8379
Absolute Humidity [g/m³]	11.0	4.3	2.4	4.9	10.4	18.9	24.0	8379

Table 4:

Statistic data of relative humidity, temperature, and absolute humidity of the reference outside climate OS 31 P3 and for comparison of outside climate of D-N-7 P7, from 30.09. Respectively 24.09.2014 until 08.09.2015.

D-N_top_tomb_P7	Maximum	Minimum	Fluctuation Range
30d moving average T	28.6	8.1	20.5
30d moving average rH	84.3	61.6	22.7
30d moving average aH	18.3	6.3	12.0
30d moving average T outside	28.3	7.9	20.4
30d moving average rH outside	85.9	63.1	22.8
30d moving average aH outside	18.8	6.5	12.3
moving 24h fluctuation rH			68.7
24h fluctuation rH			67.0

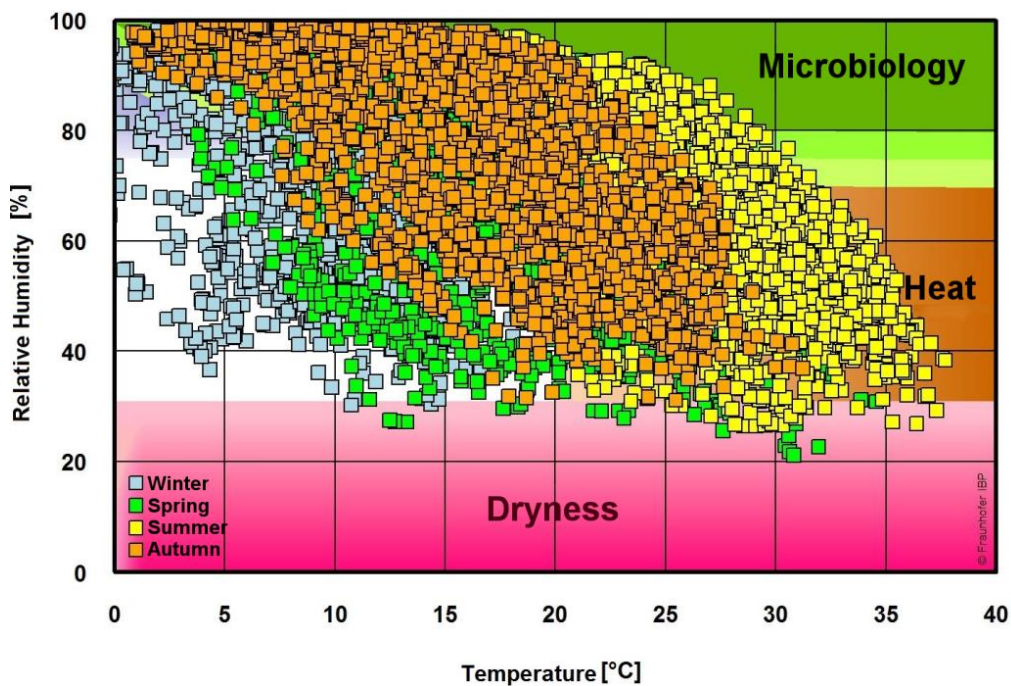


Figure 20:

Overview on the reference outside climate at tomb OS 31. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

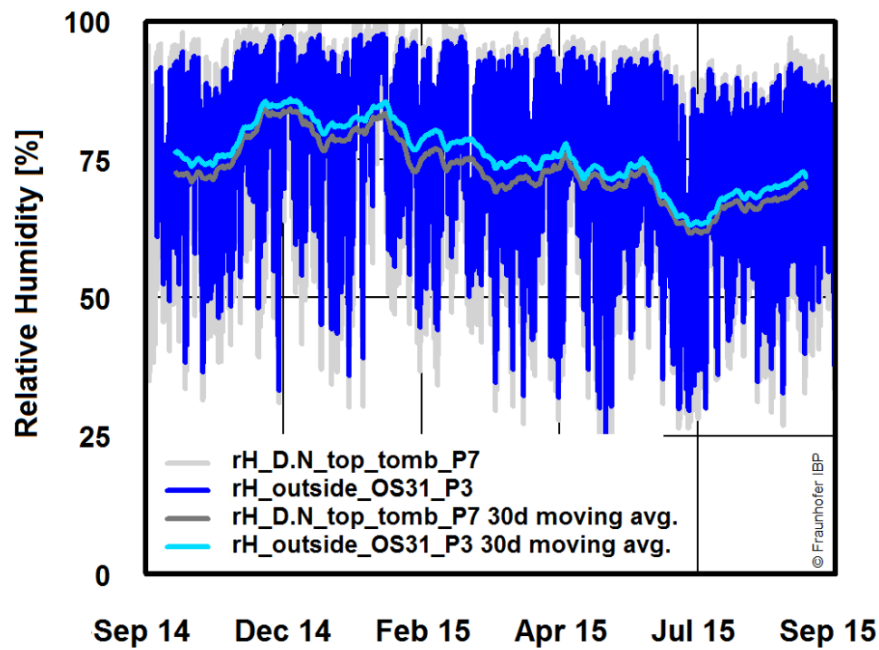


Figure 21:
Comparison of relative humidity of the reference outside climate at tomb OS 31 with local outside climate on top of tomb D-N. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

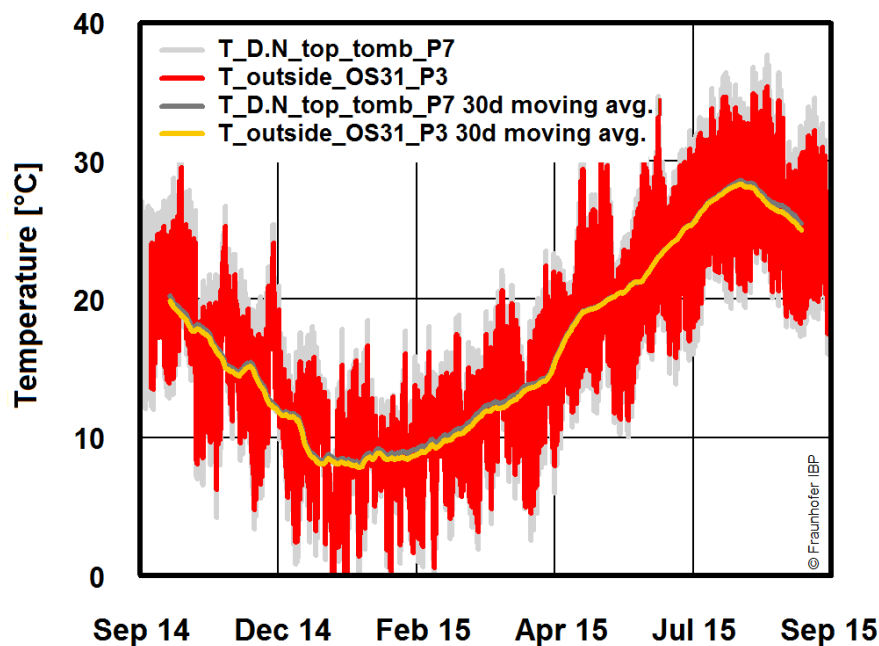


Figure 22:
Comparison of air temperature of the reference outside climate at tomb OS 31 with local outside climate on top of tomb D-N. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

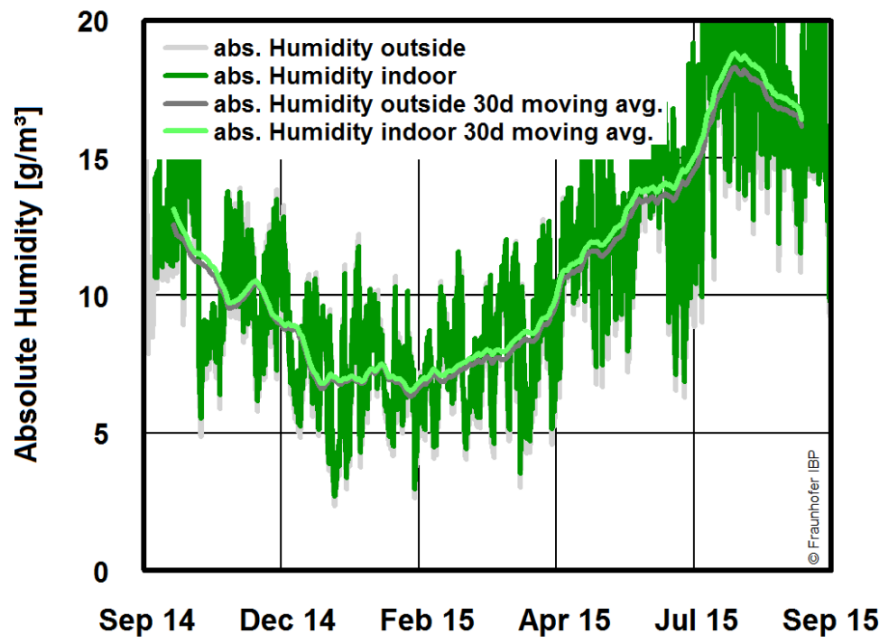


Figure 23:
Comparison of absolute humidity of the reference outside climate at tomb OS 31 with local outside climate on top of tomb D-N. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

2.2.2 Tomb D-N, Measuring Point 2, 6, 8

Tomb D-N Tin Point 6

The data logger measured the microclimate in a cave at the height of the bottom of the north wall. The opening of the cave is about 0.5 m x 0.4 m (width x height), approximately 0.8 m deep and partly covered with stone, see Figure 13. The microclimate is comparable to the reference outside climate.

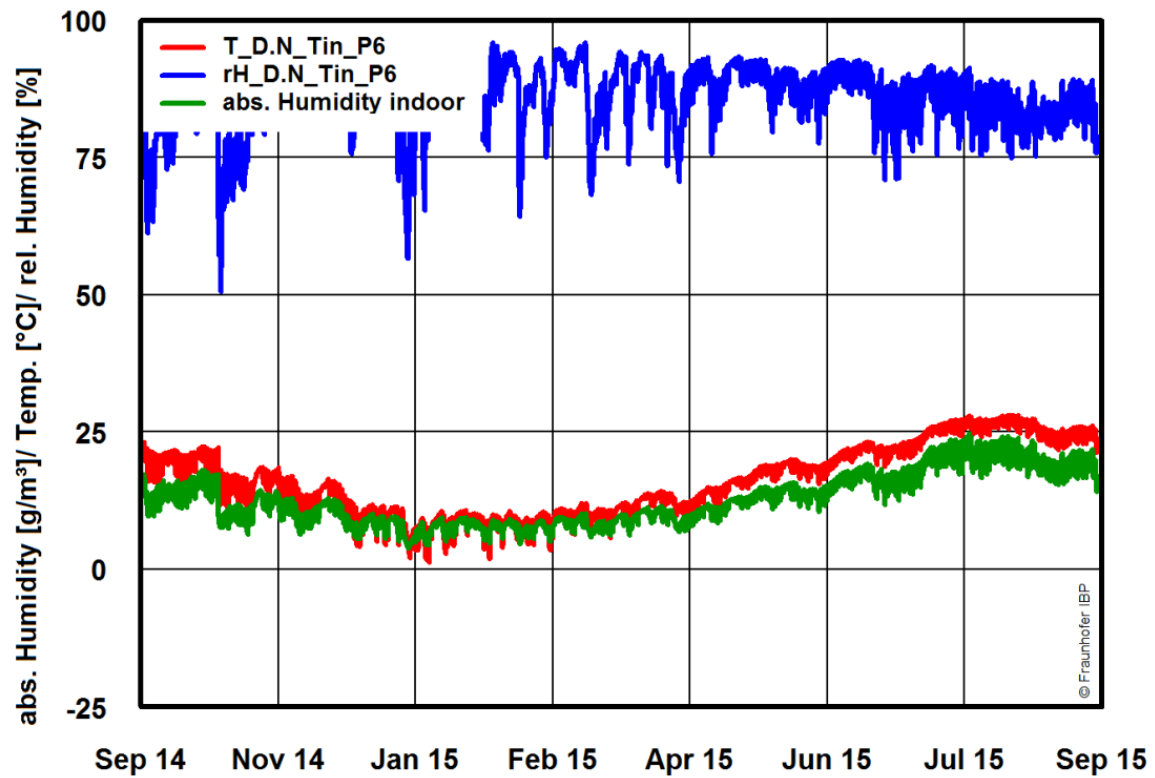


Figure 24:
Overview of the climate at tomb D-N P6 in the cave (Tin). The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Table 5:
Statistic data of the climate at tomb D-N P6 in the cave (Tin), from 24.09.2014 until 08.09.2015.

Indoor Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	86.5	6.2	50.6	74.4	87.8	94.1	96.6	8349
Temperature [°C]	16.2	6.5	1.2	6.9	15.9	26.7	28.1	8349
Absolute Humidity [g/m³]	12.7	4.9	3.8	6.4	11.7	21.7	24.7	8349

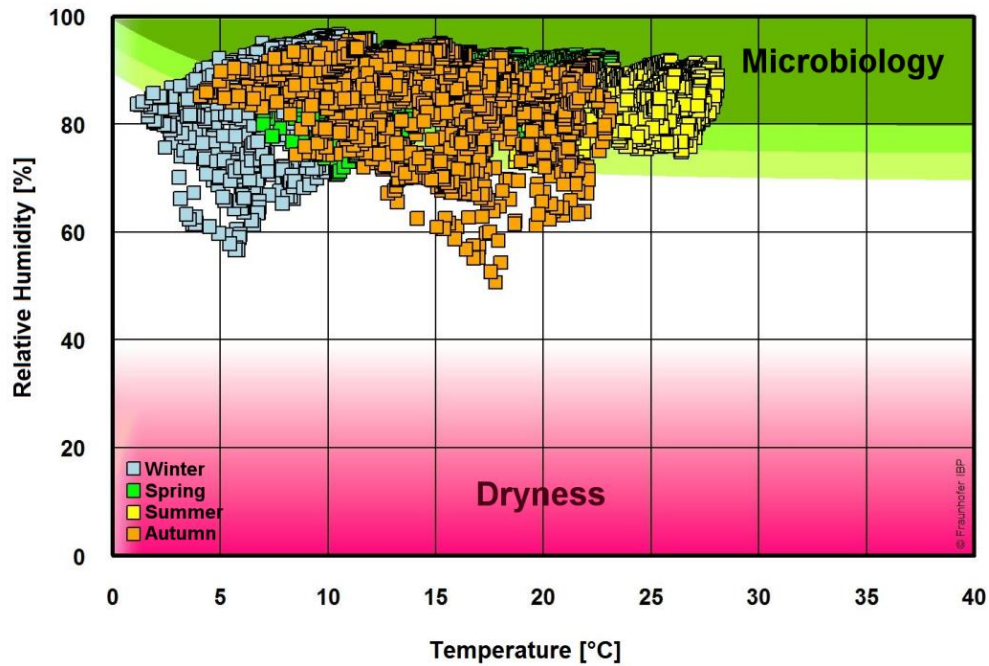


Figure 25:
Scatterplot of the climate at tomb D-N P6 in the cave (Tin). The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Table 6:
Statistic data of relative humidity, temperature, and absolute humidity of climate OS 31 P3 and for comparison of the outside climate of D-N P7, from 30.09. Respectively 24.09.2014 until 08.09.2015.

D-N_Tin_P6	Maximum	Minimum	Fluctuation Range
30d moving average T	26.7	7.7	19.0
30d moving average rH	91.2	80.3	10.9
30d moving average aH	21.4	7.2	14.2
30d moving average T outside	28.3	7.9	20.4
30d moving average rH outside	85.9	63.1	22.8
30d moving average aH outside	18.8	6.5	12.3
moving 24h fluctuation rH			31.4
24h fluctuation rH			31.1

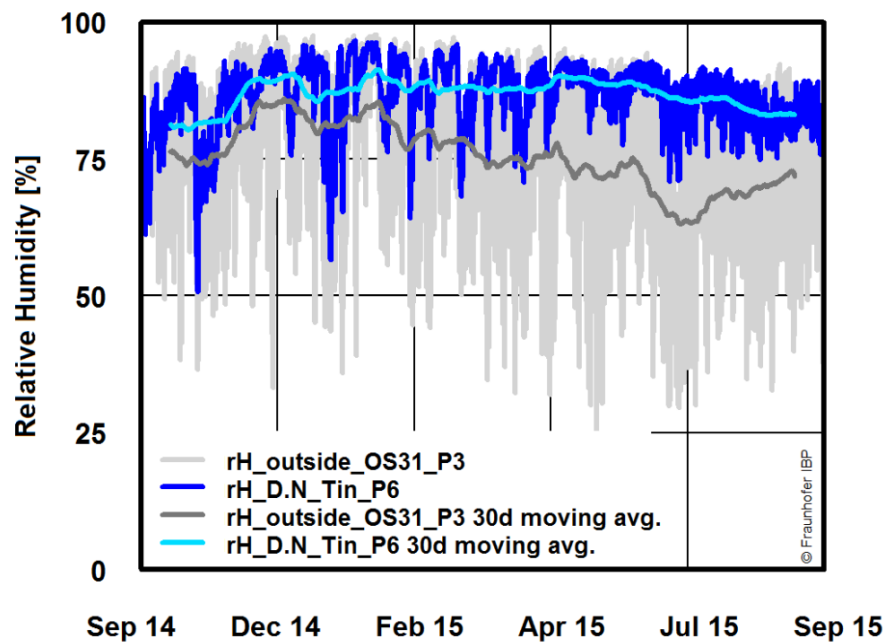


Figure 26:
Comparison of relative humidity of the climate at tomb D-N P6 in the cave (Tin) with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

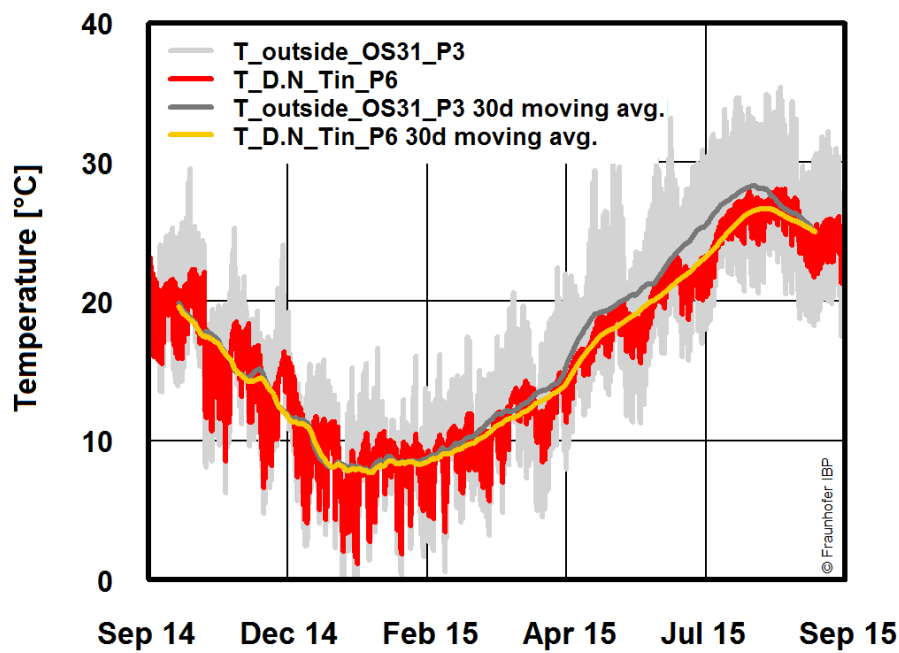


Figure 27:
Comparison of air temperature at tomb D-N P6 in the cave (Tin) with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

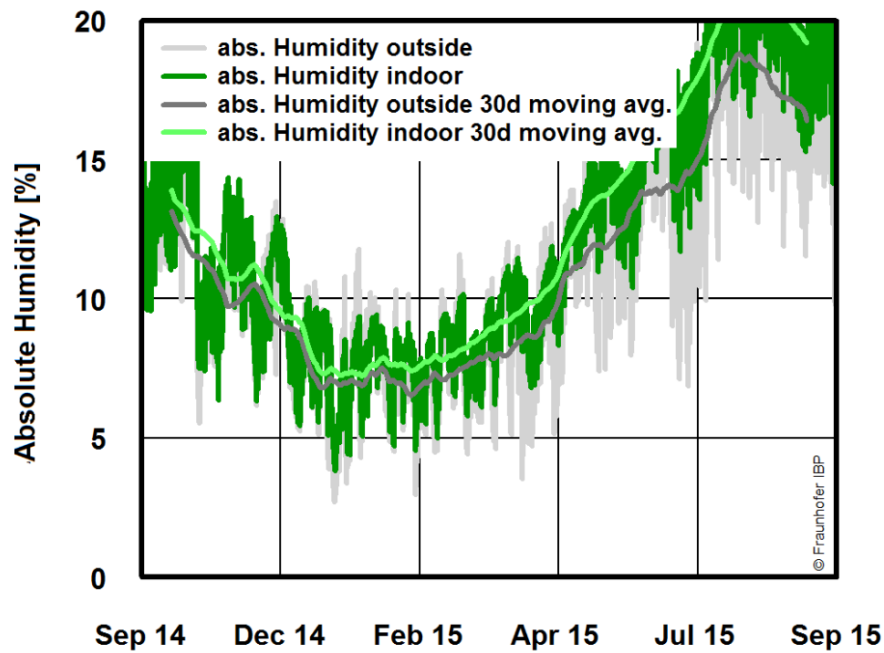


Figure 28:
Comparison of absolute humidity at tomb D-N P6 in the cave (Tin) with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Tomb D-N gap Point 8 and Point 10

At the south east side of the tomb a protective glass is mounted on the wall. The gap between glass and wall surface has a distance of about 6 cm. In this gap additional measurements of air temperature and relative humidity were made, see Figure 14.

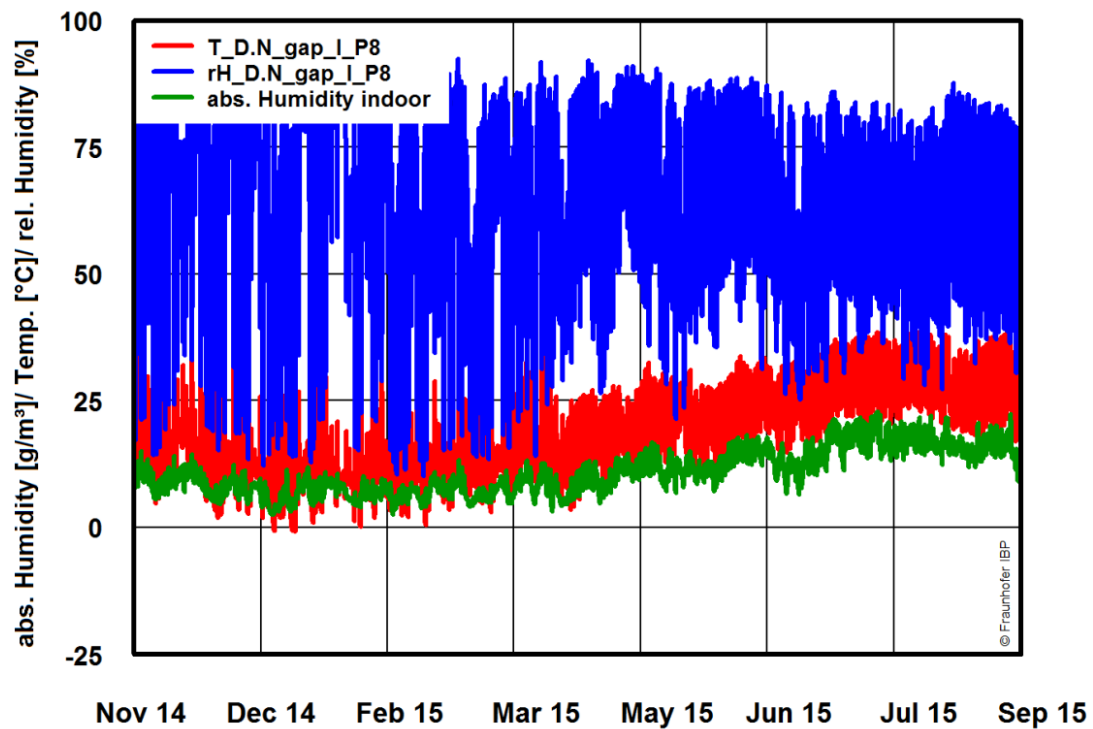


Figure 29:
Overview of the climate at tomb D-N P8 in the gap between protective glass and tomb. The graphs show the hourly mean of 10 minutes interval measured data, from 24.11.2014 until 08.09.2015.

Table 7:
Statistic data of the climate at tomb D-N P8 in the gap between protective glass and tomb, from 24.11.2014 until 08.09.2015.

Indoor Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	64.5	19.2	10.1	30.5	67.7	88.9	97.3	7168
Temperature [°C]	19.2	9.4	-0.8	5.6	18.8	35.6	46.0	7168
Absolute Humidity [g/m³]	10.8	4.4	2.4	4.7	9.9	18.9	22.9	7168

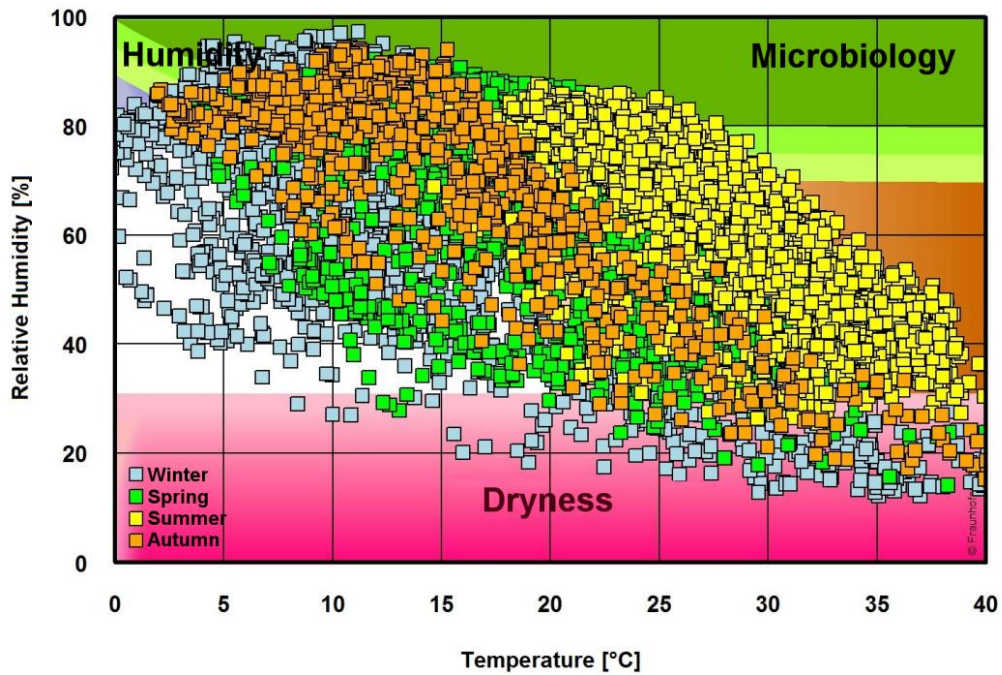


Figure 30:
Scatterplot of the climate at tomb D-N P8 in the gap between protective glass and tomb. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Table 8:
Statistic data of relative humidity, temperature, and absolute humidity of the reference outside climate OS 31 P3 and comparison with D-N P8 in the gap between protective glass and tomb, from 30.09. Respectively 24.09.2014 until 08.09.2015.

D-N_gap_I_P8	Maximum	Minimum	Fluctuation Range
30d moving average T	30.1	10.6	19.5
30d moving average rH	73.4	57.5	15.9
30d moving average aH	17.9	6.2	11.7
30d moving average T outside	28.3	7.9	20.4
30d moving average rH outside	85.9	63.1	22.8
30d moving average aH outside	18.8	6.5	12.3
moving 24h fluctuation rH			80.8
24h fluctuation rH			76.6

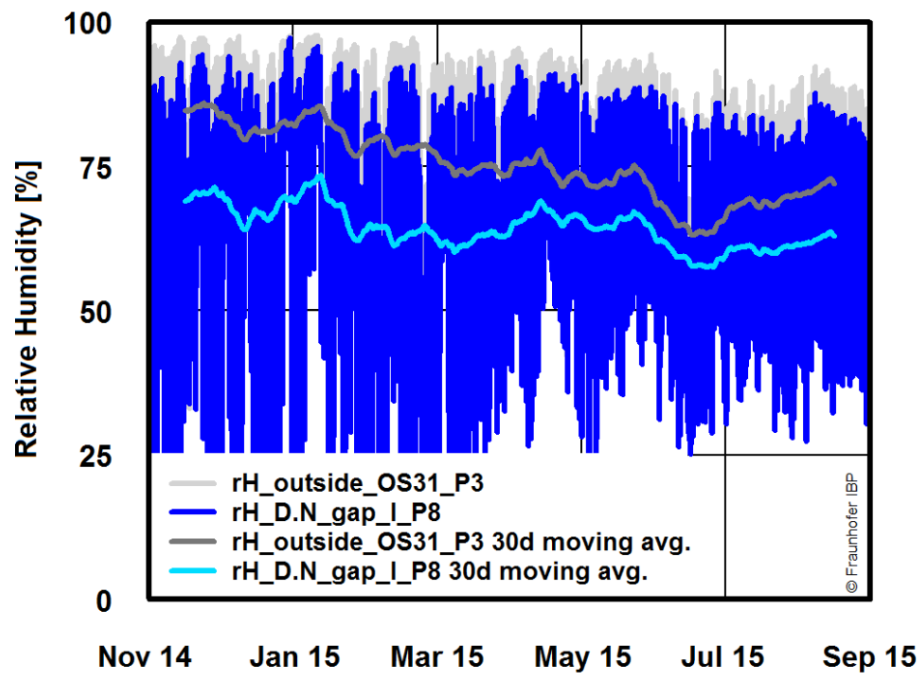


Figure 31:
Comparison of relative humidity of the climate at tomb D-N P8 in the gap between protective glass and tomb with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

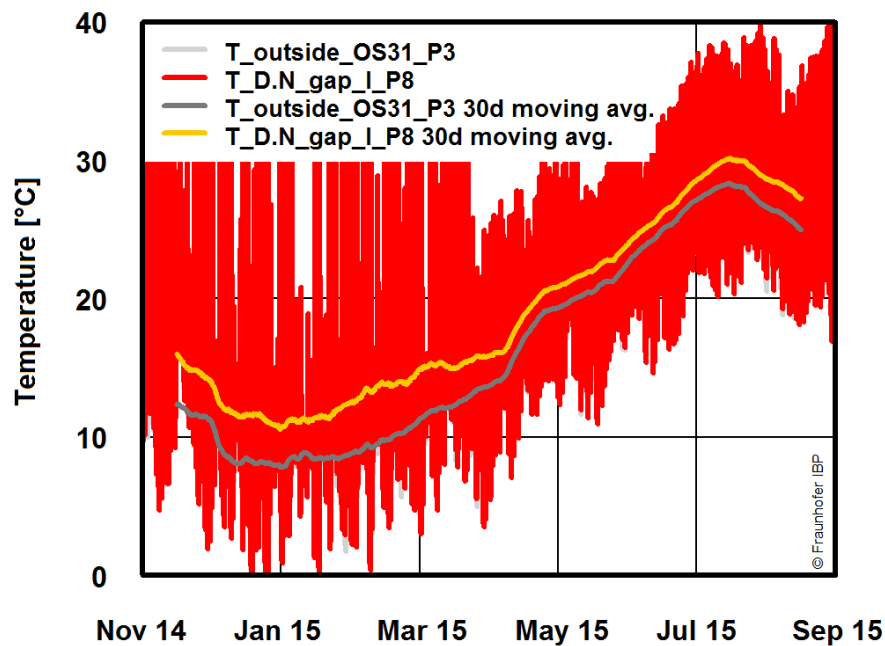


Figure 32:
Comparison of air temperature at tomb D-N P8 in the gap between protective glass and tomb with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

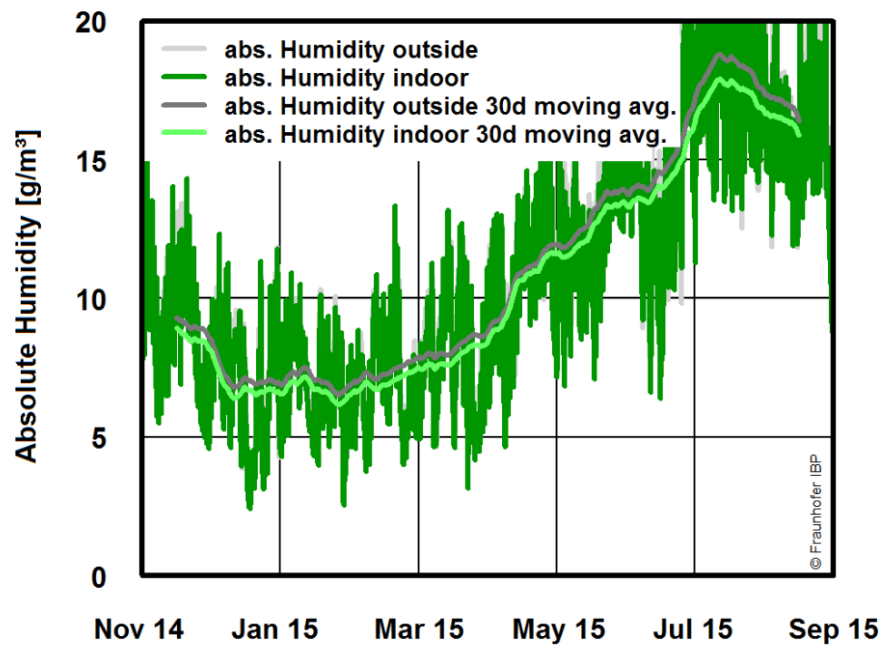


Figure 33:
Comparison of absolute humidity at tomb D-N P8 in the gap between protective glass and tomb with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Tomb D-N gap Point 10

The first measurement in the gap with Point 8 was overestimating the temperature course and in consequence underestimating the relative humidity due to incorrect construction of irradiation shield. The additional measurement with an improved radiation shield showed better results on climate measurement.

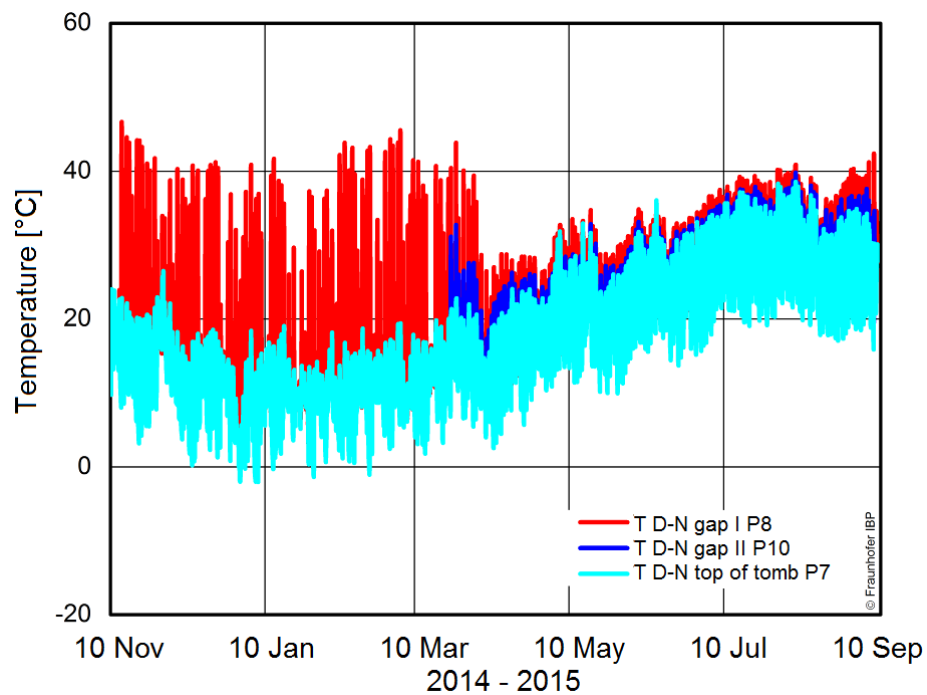


Figure 34:

Comparison of air temperature at tomb D-N P8 and P10 in the gap between protective glass and tomb with local outside climate P7 on top of the tomb. The graphs show the 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Tomb D-N surface Temperature Point 2

At the south east side of the tomb a protective glass is mounted on the wall. The gap between glass and wall surface has a distance of about 6 cm. On the surface of the tomb two temperature measurements were made (behind the protective glass and underneath); see Figure 35 to Figure 37.

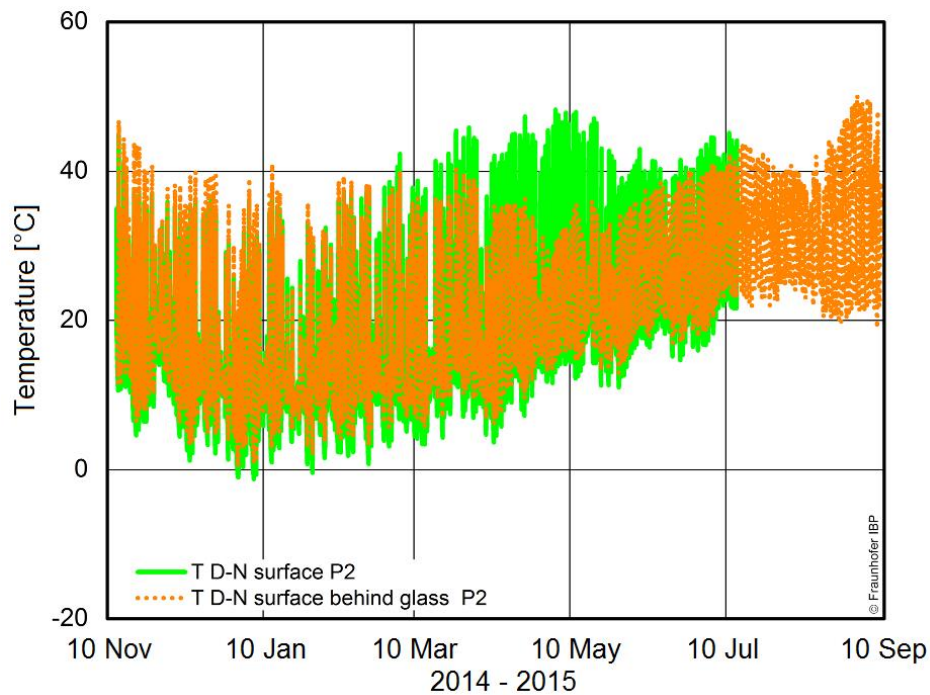


Figure 35:
Overview of the surface temperature at tomb D-N P2. The graphs show the 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

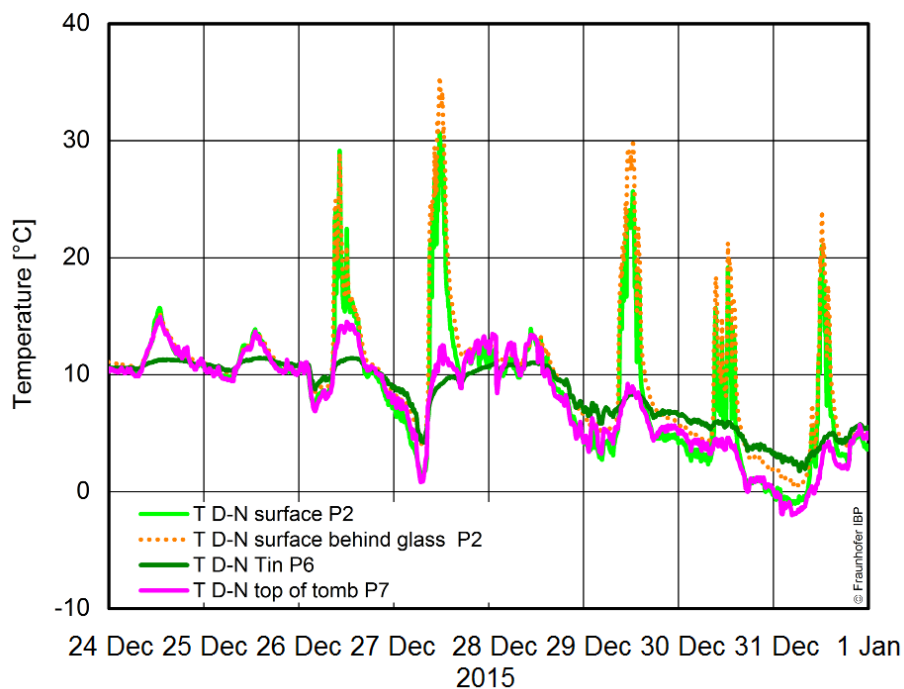


Figure 36:
Detail of the surface temperature at tomb D-N P2, supplemented by P6 and P10. The graphs show the 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

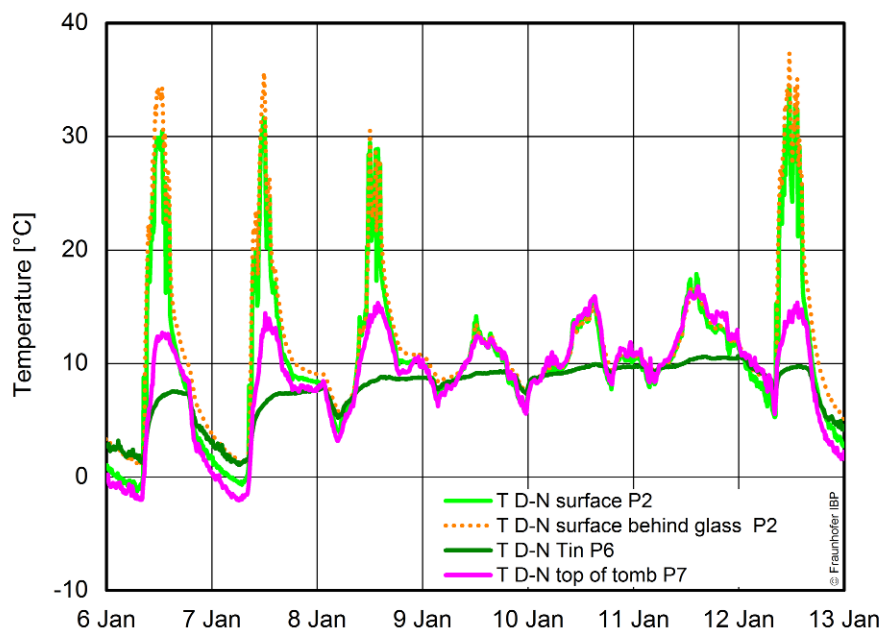


Figure 37:
Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7.
The graphs show the 10 minutes interval measured data, from 06.01.2015 until 13.01.2015.

Surface temperature and calculated relative humidity D-N P2 behind protective glass

With the measured absolute humidity of D-N P7 top of tomb and the surface temperature measured at D-N P2 behind the protective glass, it is possible to calculate the relative humidity on the surface at P2.

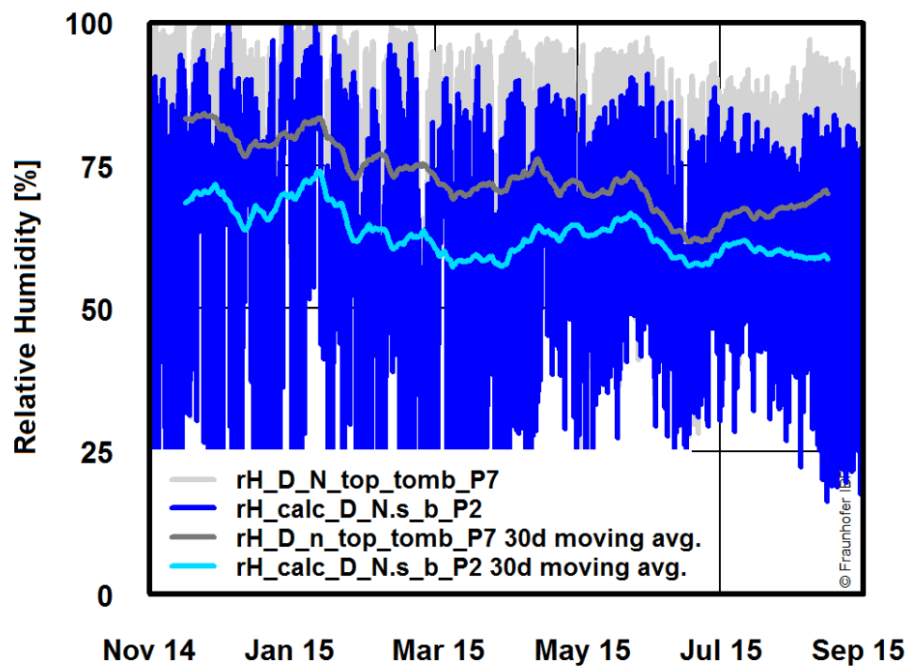


Figure 38:

The graphs show the relative humidity at top of the tomb P7 with the calculated relative humidity on the surface D-N P2 behind protective glass. The graphs show the hourly mean of the 10 minutes interval measured data, from 14.11.2015 until 08.09.2015.

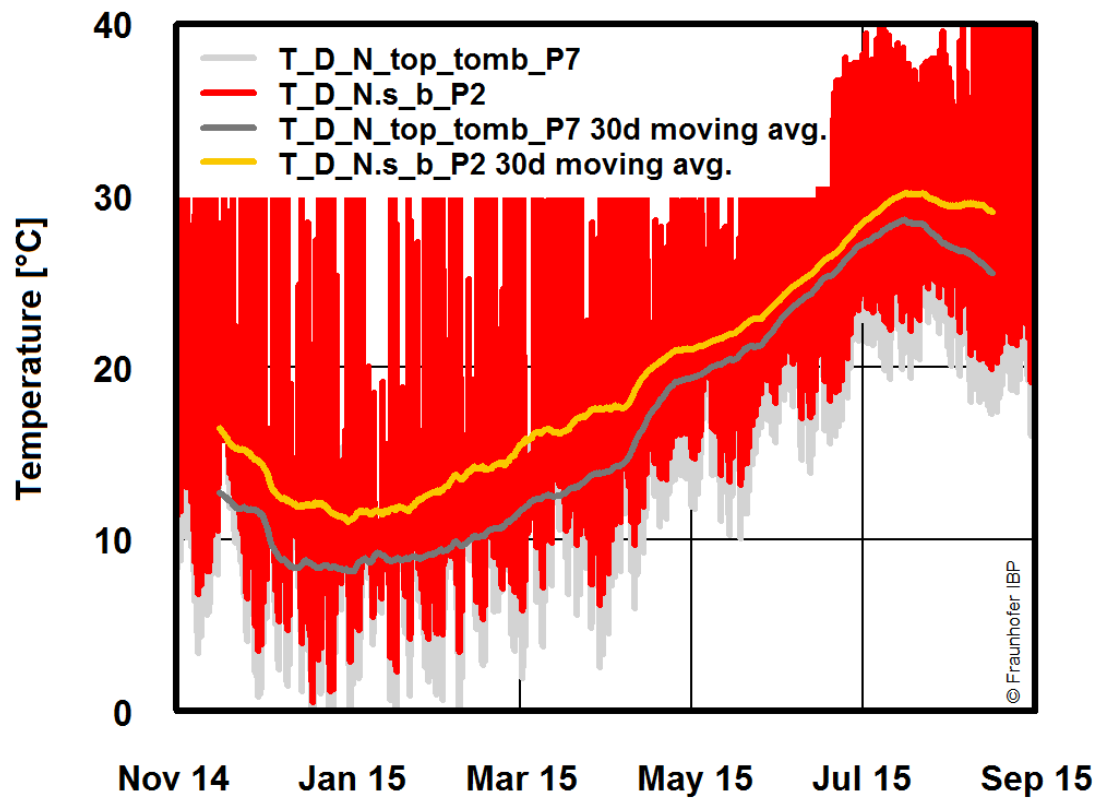


Figure 39:
Comparison of surface temperature at tomb D-N P2 behind the protective glass with local outside climate D-N P7. The graphs show the hourly mean of the 10 minutes interval measured data, from 14.11.2015 until 08.09.2015.

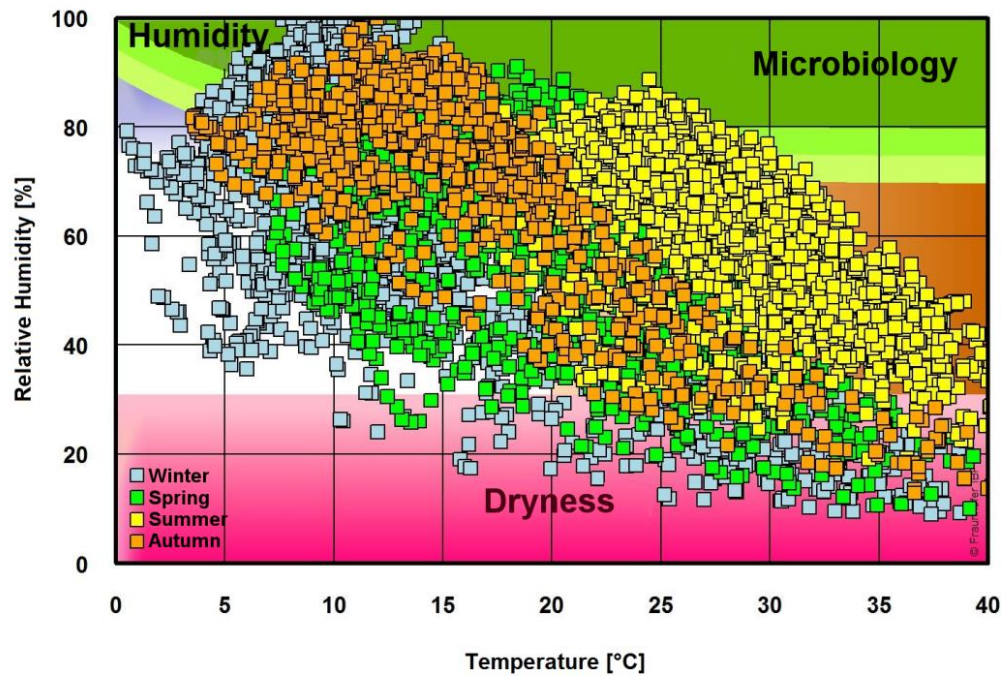


Figure 40:
Surface temperature at tomb D-N P2 behind protective glass with calculated relative humidity on the surface. The graphs show the hourly mean of the 10 minutes interval measured data, from 14.11.2015 until 08.09.2015.

Table 9:
Statistic data of the climate at tomb D-N P2 on the surface behind protective glass, from 14.11.2014 until 08.09.2015.

Indoor Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	63.1	19.2	9.0	26.7	66.5	89.5	100.0	7176
Temperature [°C]	19.8	9.0	0.5	7.1	19.4	35.1	49.4	7176
Absolute Humidity [g/m ³]	10.9	4.5	2.4	4.7	10.1	19.0	23.9	7176

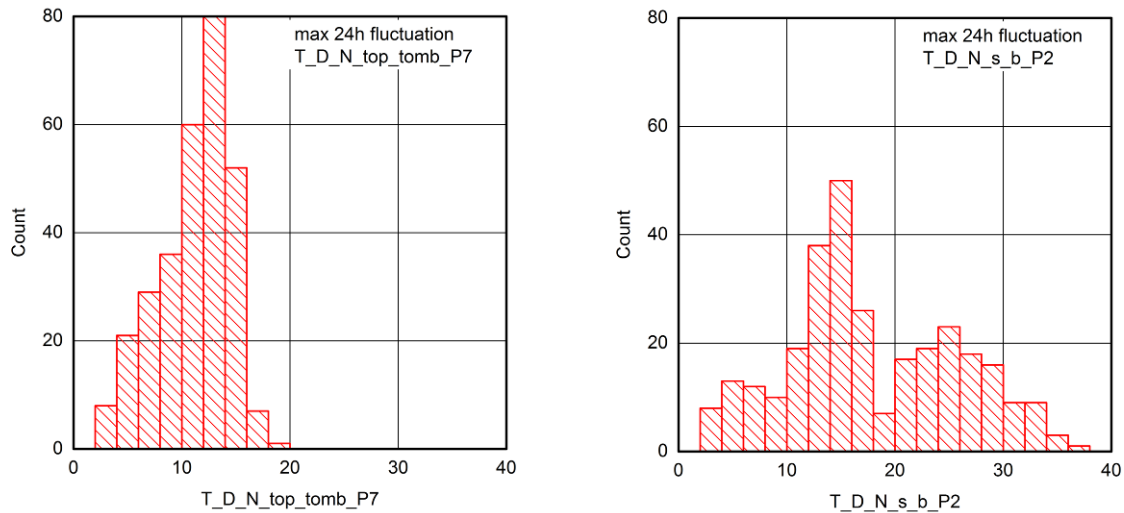


Figure 41:
Histogram of maximum fluctuation of temperature within 24 hours of temperature within 2 K classes for the local outside climate on top of the tomb P7 and surface temperature of the tomb behind the protective glass P2. The graphs show the hourly mean of the 10 minutes interval measured data, from 14.11.2015 until 08.09.2015.

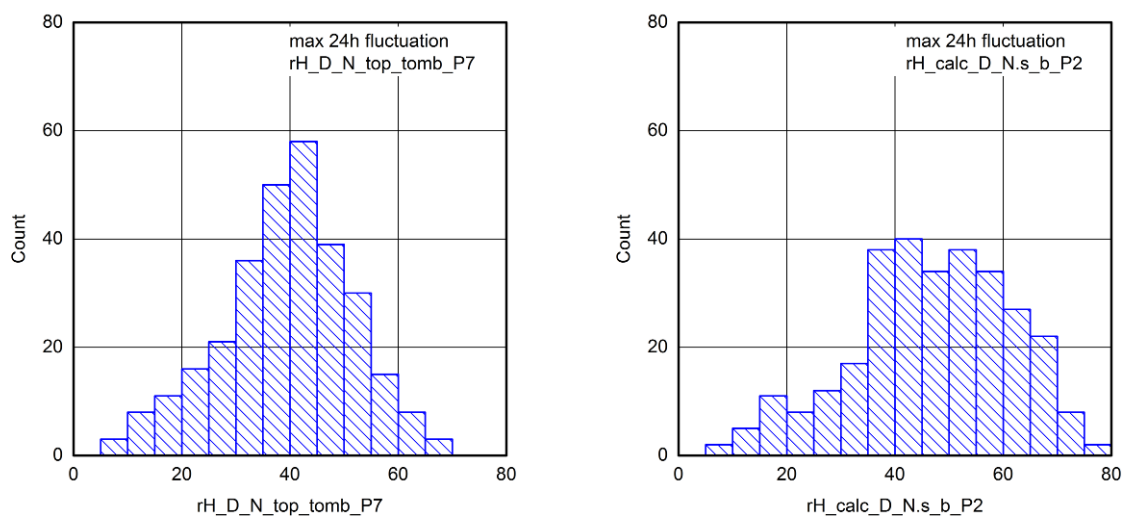


Figure 42:
Histogram of maximum fluctuation of relative humidity within 24 hours of relative humidity within 5 % rH classes for the local outside climate on top of the tomb P7 and calculated relative humidity on the surface of the tomb behind the protective glass P2. The graphs show the hourly mean of the 10 minutes interval measured data, from 14.11.2015 until 08.09.2015.

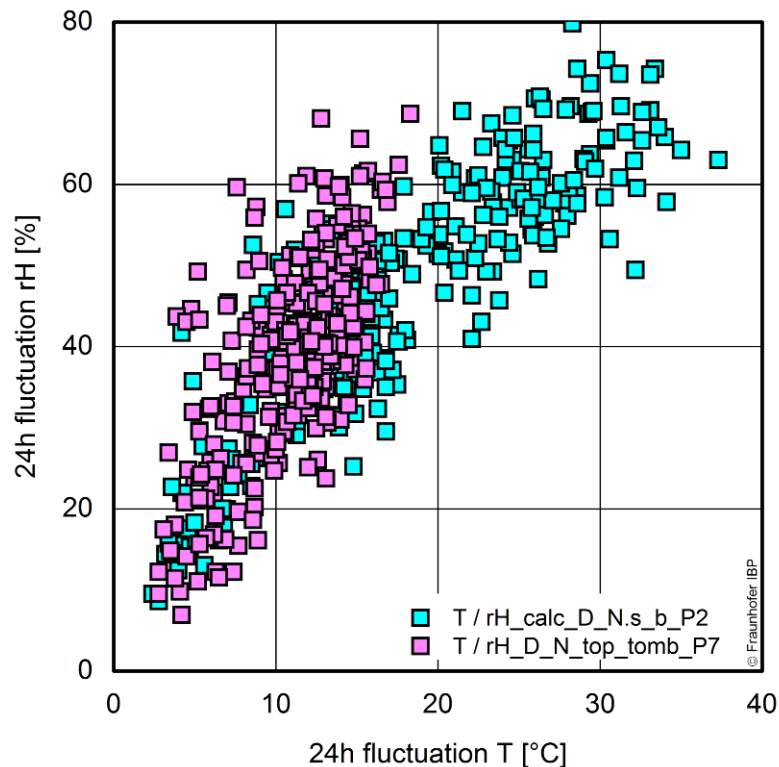


Figure 43:

Comparison of maximum fluctuation of relative humidity and temperature within 24 hours for the local outside climate on top of the tomb P7 and the surface behind the protective glass P2 from 14.11.2015 until 08.09.2015.

Tomb D-N surface Temperature Point 2 with Point 7 and Point 10

The surface temperature is compared to the air temperature in the gap and air temperature on top of the tomb. Additionally the air temperature of the cave is shown.

Shadowing of the wall surface

the temperature course of the surface temperature behind the protective glass lies about 10 to 15 Kelvin higher compared to the air gap temperature. This is explained by heating by sun radiation; see Figure 44 and Figure 45. The temperature course rise and decline of temperature depending on sun position. The air gap temperature is about 5 Kelvin higher compared to the air temperature on top of the tomb. On cloudy days with low direct sun radiation the temperature course is almost similar to the temperature on top of the tomb, see Figure 45. In Figure 46 the temperature course of the surface temperature is not smooth anymore. The protective roof is partially shadowing during daytime the temperature sensor. The effect is also recognizable in Figure 44. The temperature rise of the surface temperature is declining compared to outside temperature on top of the tomb. Some month later with beginning autumn the az-

imuth of the sun declines and the shadowing vanish more. In consequence the temperature shift rises again.

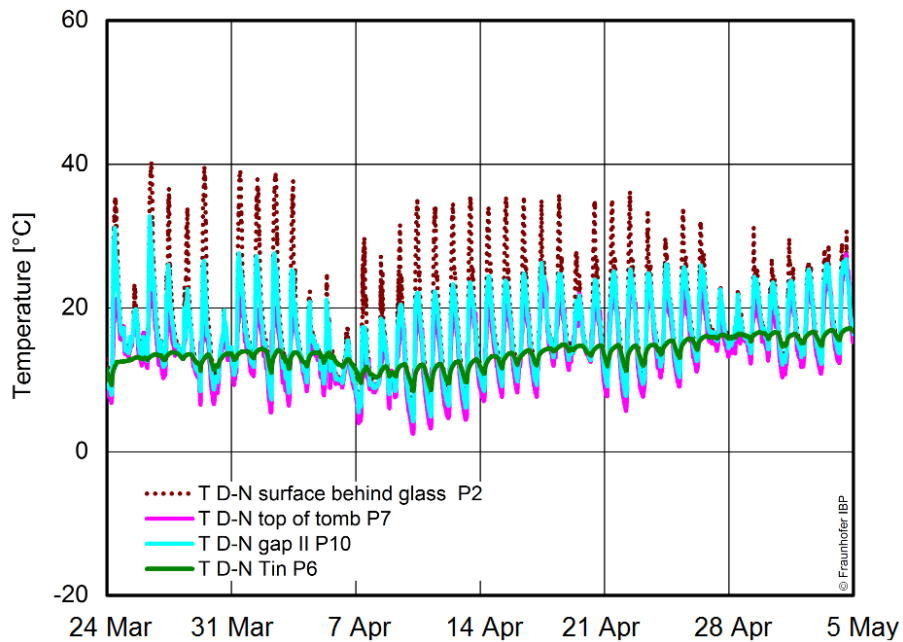


Figure 44:
Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 24.03.2015 until 05.05.2015.

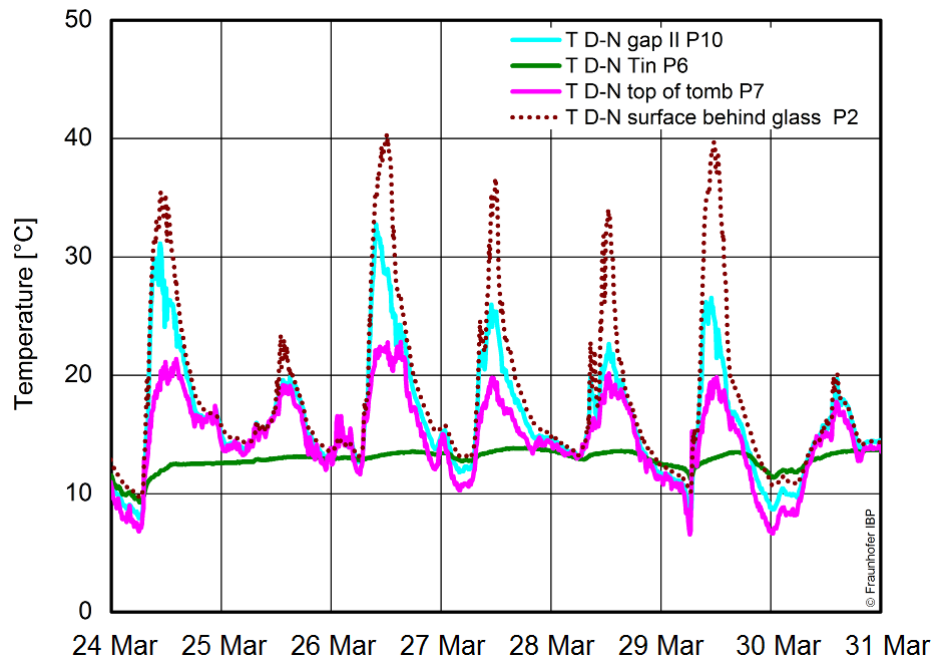


Figure 45:

Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 24.03.2015 until 31.03.2015. Sun is standing low. Sunlight for a long period directly on south wall.

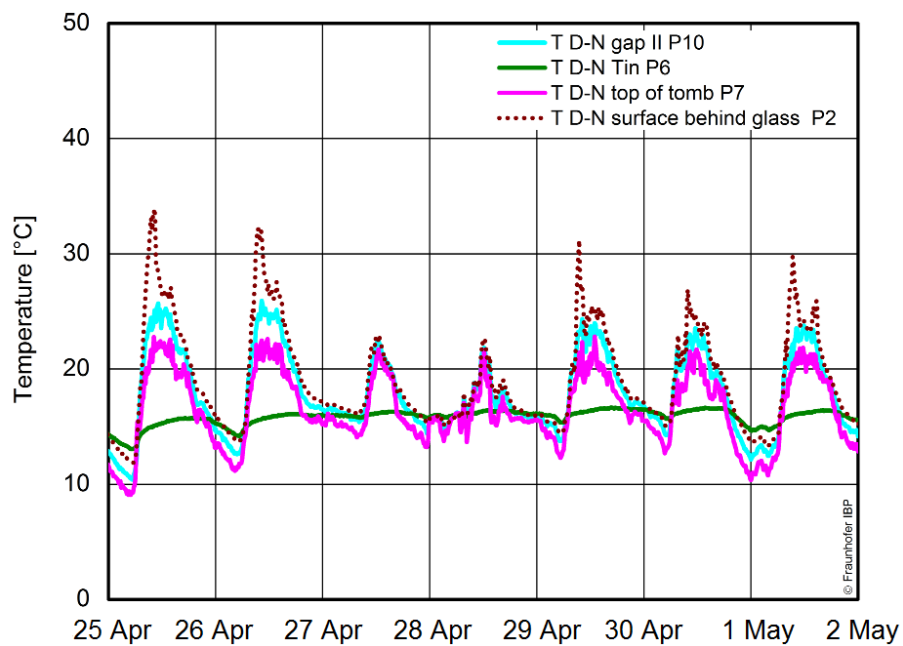


Figure 46:

Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 25.04.2015 until 02.05.2015. Sun is standing higher. During the afternoon period there is shading on the south wall.

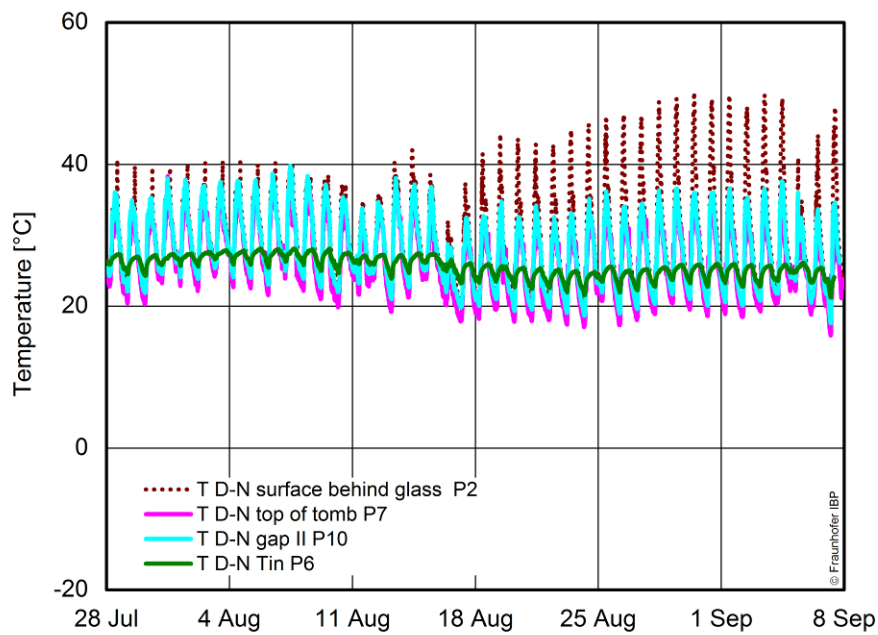


Figure 47:
Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 28.07.2015 until 08.09.2015.

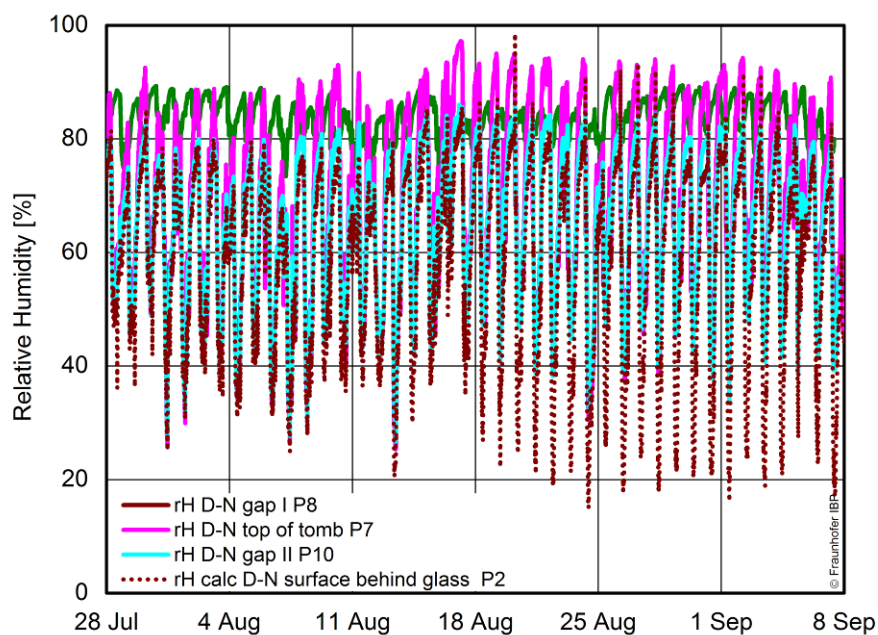


Figure 48:
Detail of the calculated relative humidity of the surface at tomb D-N P2 supplemented by rH of P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 28.07.2015 until 08.09.2015.

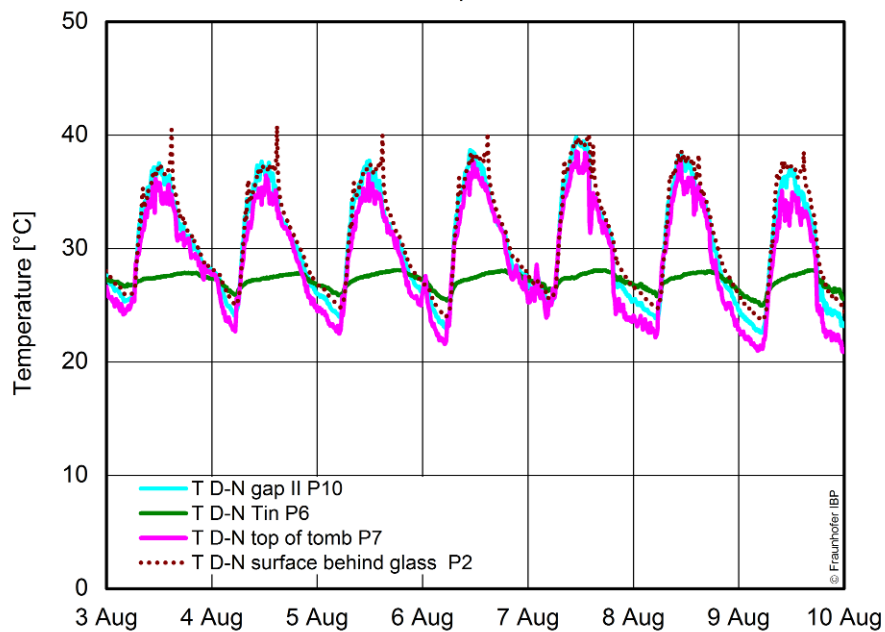


Figure 49:
Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 03.008.2015 until 10.08.2015.

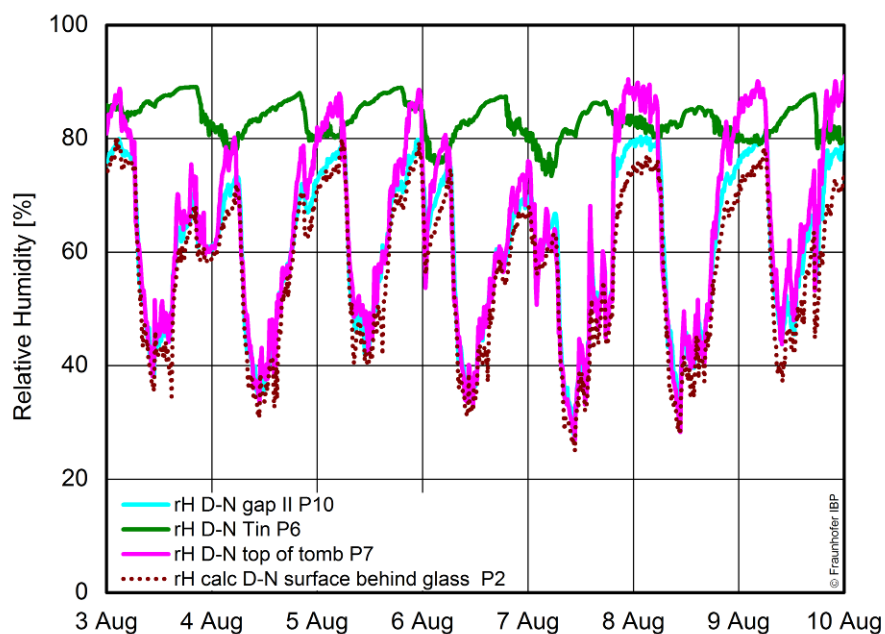


Figure 50:
Detail of the calculated relative humidity of the surface at tomb D-N P2 supplemented by rH of P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 03.008.2015 until 10.08.2015.

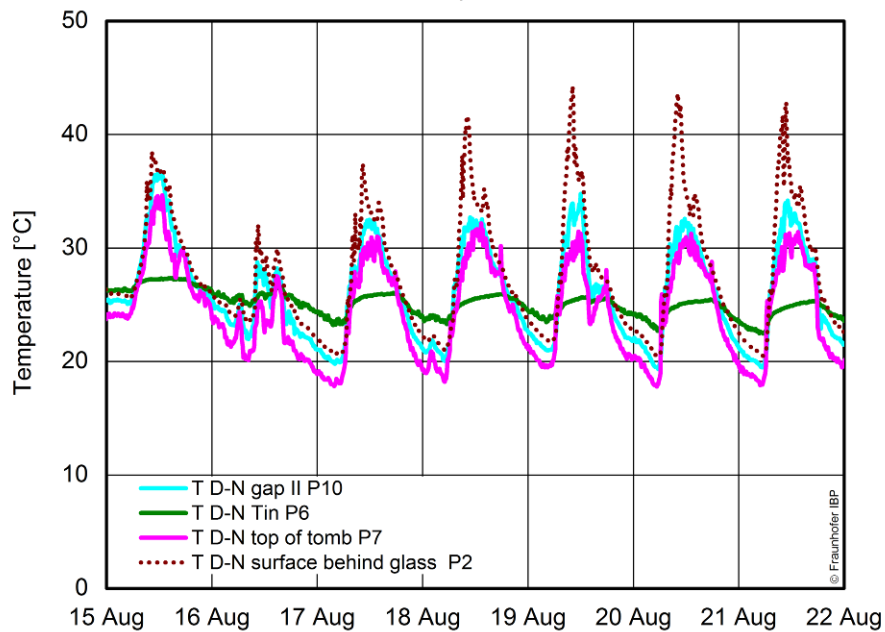


Figure 51:
Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 15.08.2015 until 22.08.2015.

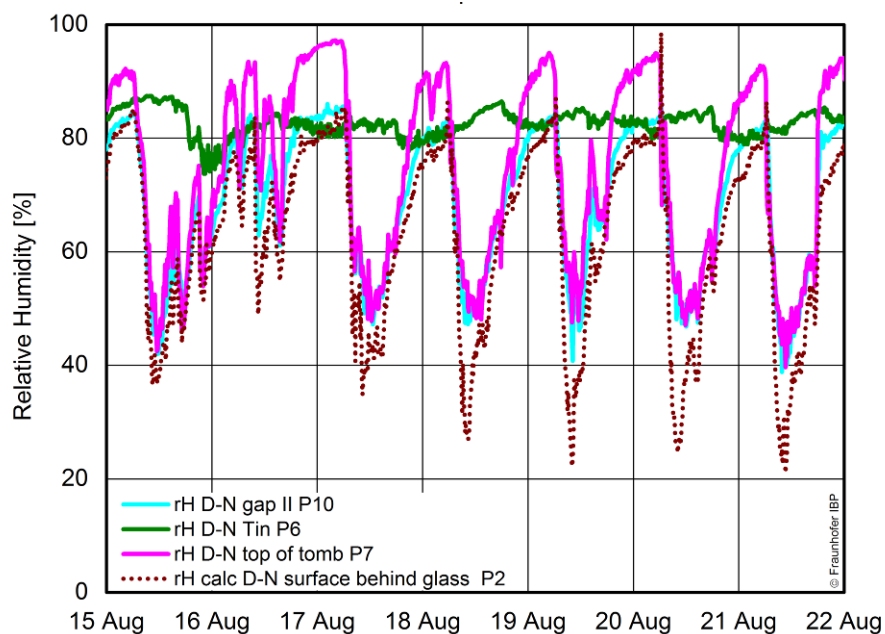


Figure 52:
Detail of the calculated relative humidity of the surface at tomb D-N P2 supplemented by rH of P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 15.08.2015 until 22.08.2015.

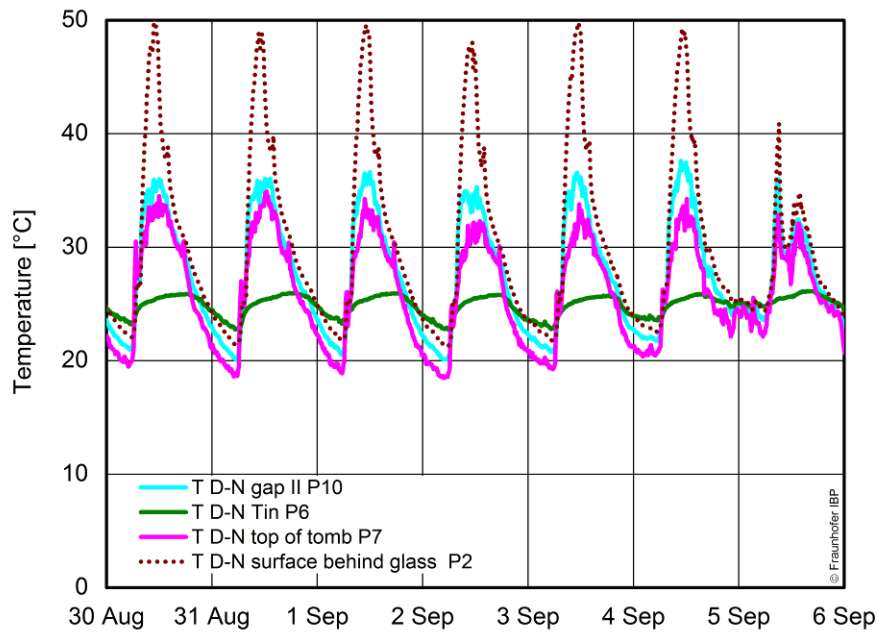


Figure 53:
Detail of the surface temperature at tomb D-N P2 supplemented by P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 30.08.2015 until 06.09.2015.

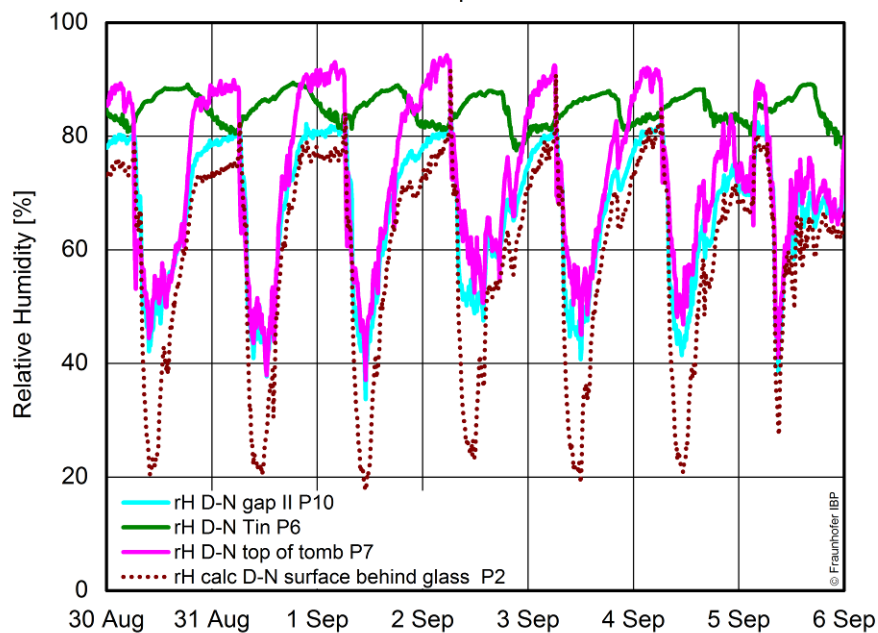


Figure 54:
Detail of the calculated relative humidity of the surface at tomb D-N P2 supplemented by rH of P6 and P7 and P10. The graphs show the 10 minutes interval measured data, from 30.08.2015 until 06.09.2015.

2.2.3 Tomb ES 7 Measuring Point 4a

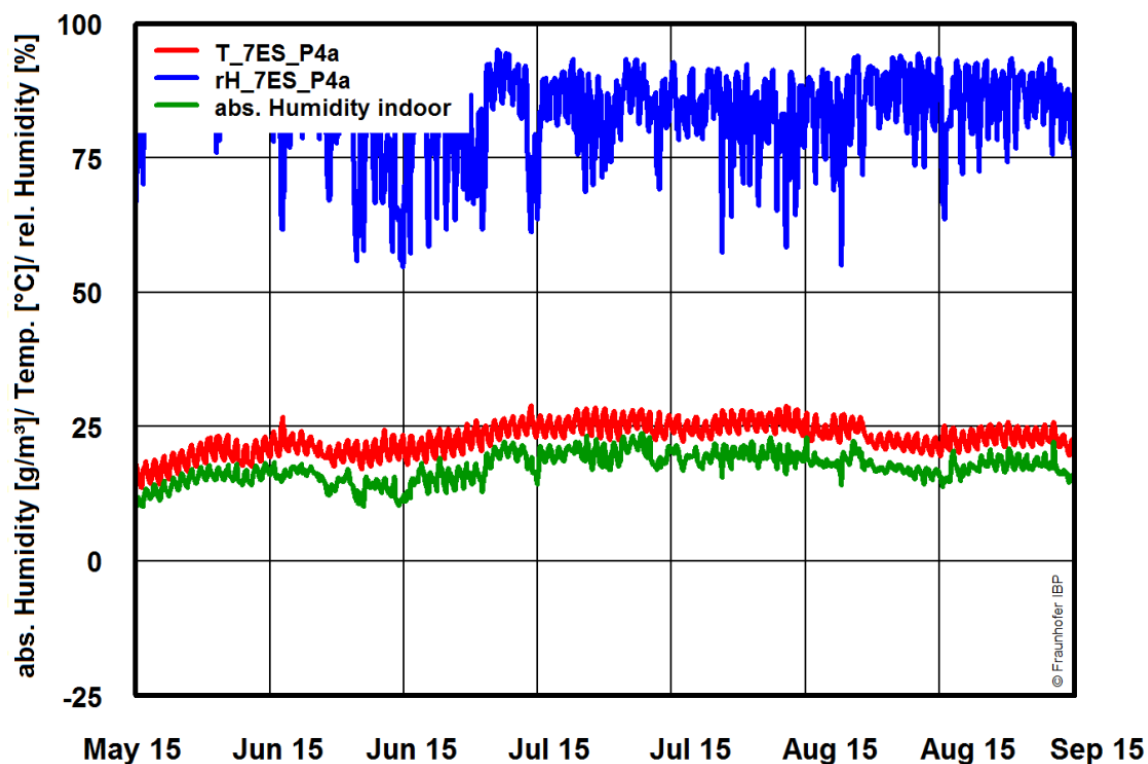


Figure 55:
Overview of the climate in tomb ES 7 P4a on a cornice. The graphs show the hourly mean of 10 minutes interval measured data, from 28.05.2015 until 08.09.2015.

Table 10:
Statistic data of the climate in tomb ES 7 P4a on a cornice, from 28.05.2015 until 08.09.2015.

Indoor Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	84.6	7.9	54.8	68.1	86.3	93.9	97.1	2454
Temperature [°C]	22.8	2.8	13.6	18.0	23.0	27.3	28.9	2454
Absolute Humidity [g/m³]	17.3	2.6	9.9	12.5	17.4	21.4	23.8	2454

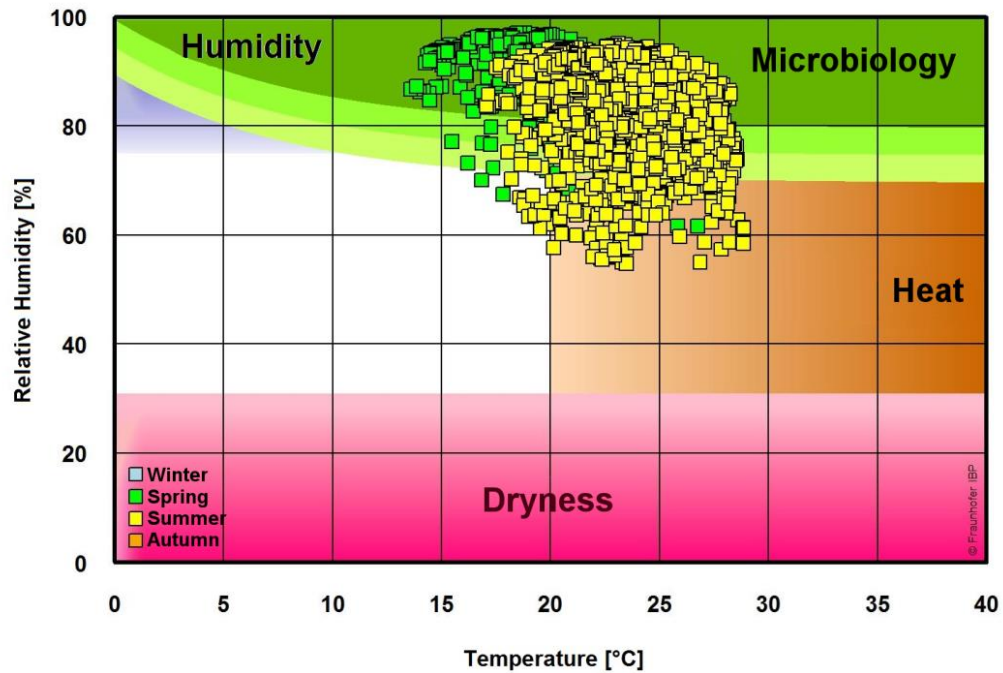


Figure 56:
Scatterplot of the climate in tomb ES 7 P4a on a cornice. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

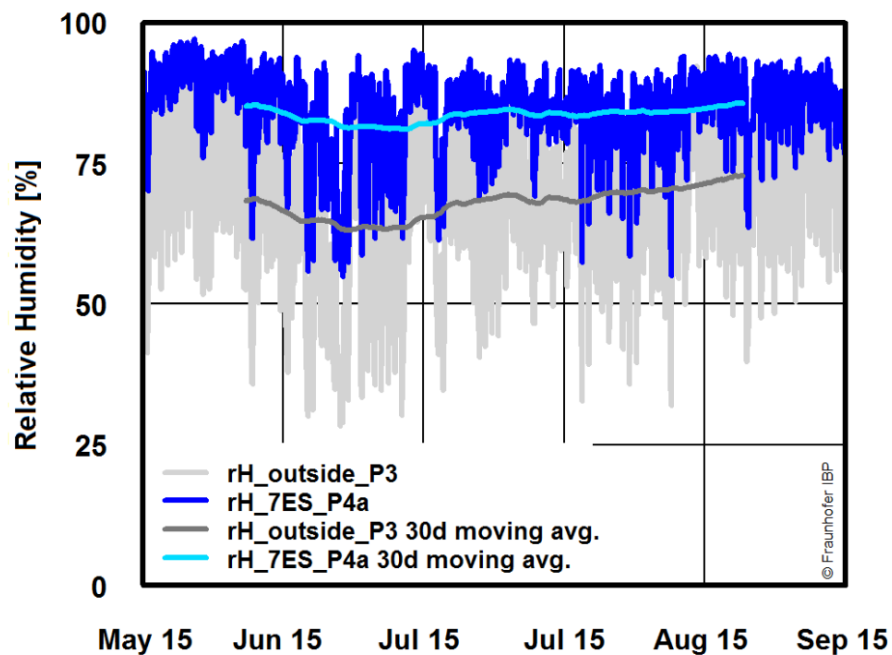


Figure 57:
Comparison of relative humidity of the climate in tomb ES 7 P4a on a cornice with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 28.05.2015 until 08.09.2015.

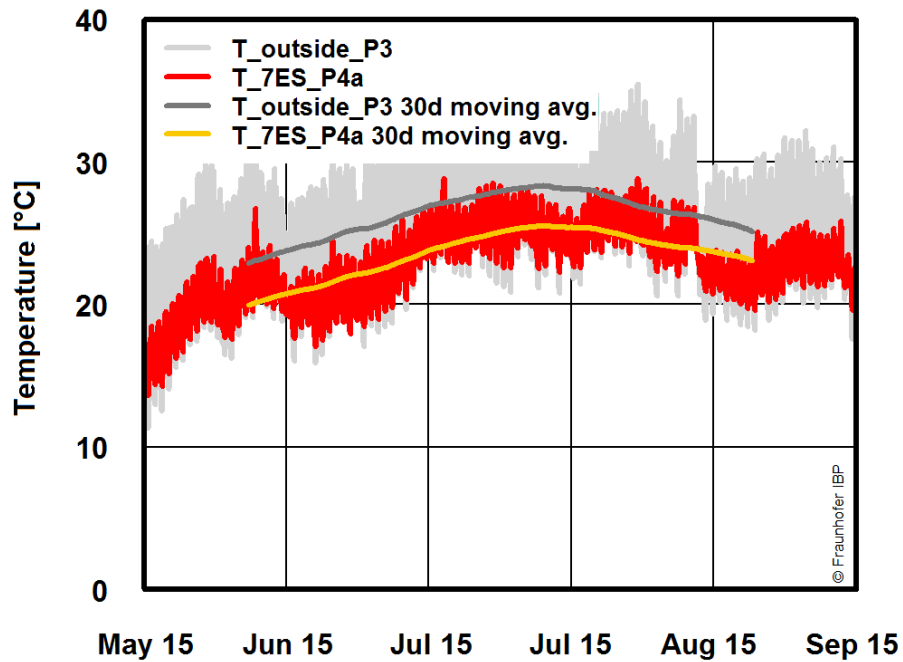


Figure 58:
Comparison of air temperature in tomb ES 7 P4a on a cornice with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 28.05.2015 until 08.09.2015.

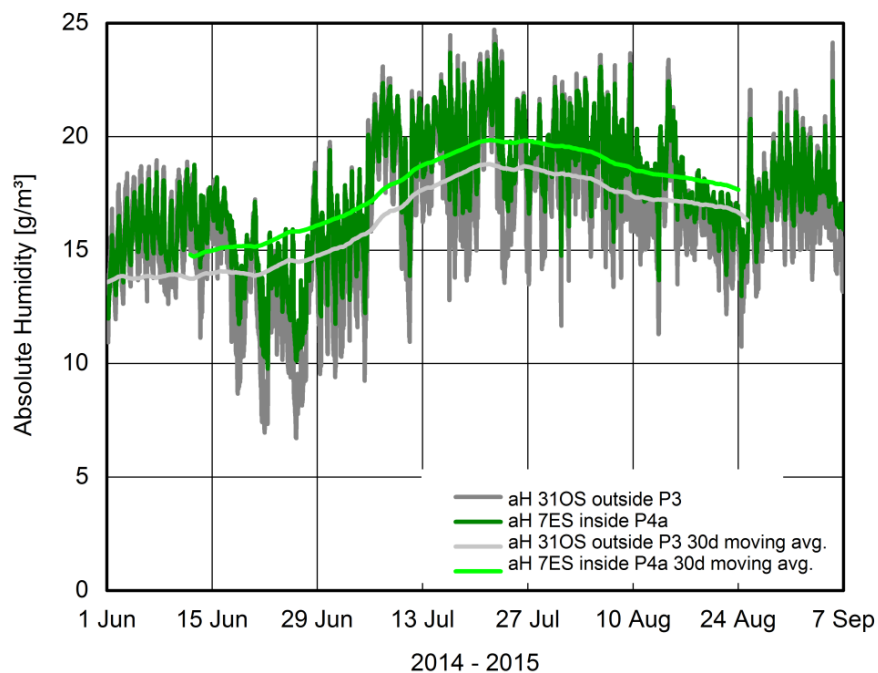


Figure 59:
Comparison of absolute humidity in tomb ES 7 P4a on a cornice with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 28.05.2015 until 08.09.2015.

2.2.4 ES 9, Measuring Point 4 and 11 compared to Measuring Point 3

The climate measurement on the front of the tomb on a cornice behind the protective glass is compared to the climate on the opposite side of the wall, on its back side. The wall is additionally protected by a roof, supported by a scaffold; see Figure 4, Figure 6 and Figure 7. Measurement Point 4 and 11 are still positioned on the same place, only the data logger was changed.

Figure 60 to Figure 64 show the climate and the basic statics of local climate 9 ES P4 P11 in comparison to the reference outside climate OS 31 P3.

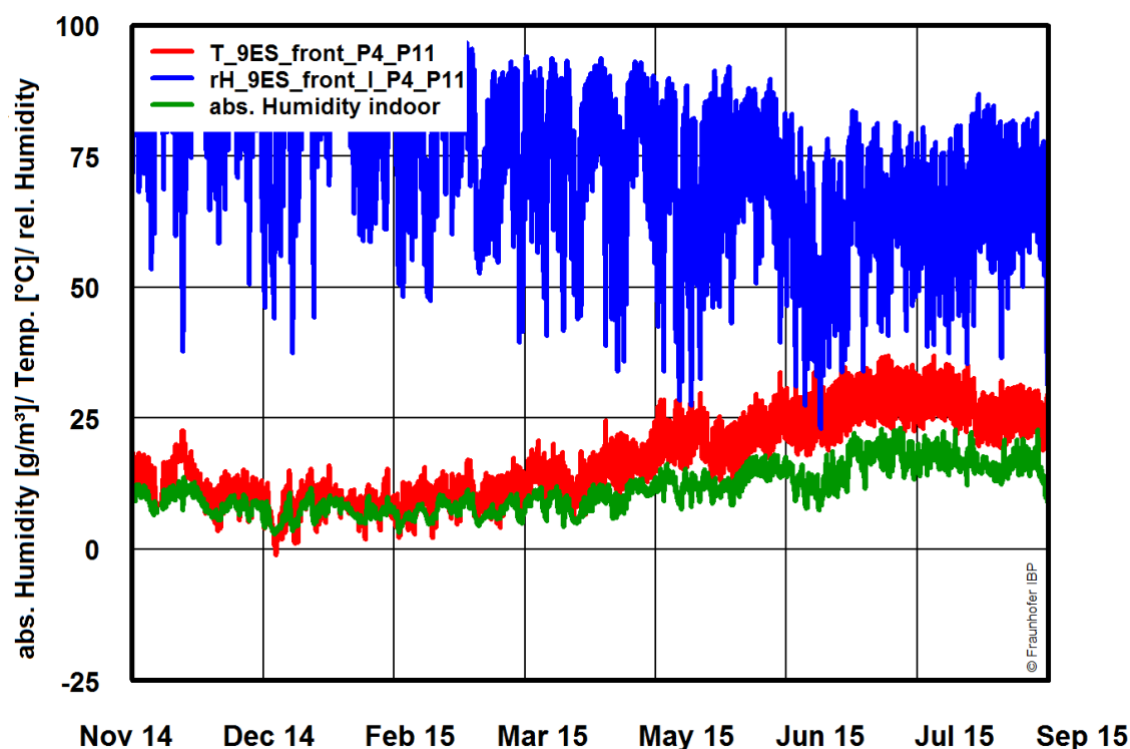


Figure 60:
Overview of the climate at tomb 9 ES P4 P11 in the gap between protective glass and tomb. The graphs show the hourly mean of 10 minutes interval measured data, from 14.11.2014 until 08.09.2015.

Table 11:
Statistic data of the climate at tomb 9 ES P4 P11 in the gap between protective glass and tomb, from 14.11.2014 until 08.09.2015.

Indoor Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	74.2	14.8	23.0	47.3	75.6	94.5	97.5	7130
Temperature [°C]	17.0	8.1	-1.1	5.7	15.7	30.8	37.6	7130
Absolute Humidity [g/m³]	11.2	4.3	2.7	5.3	10.4	19.1	23.2	7130

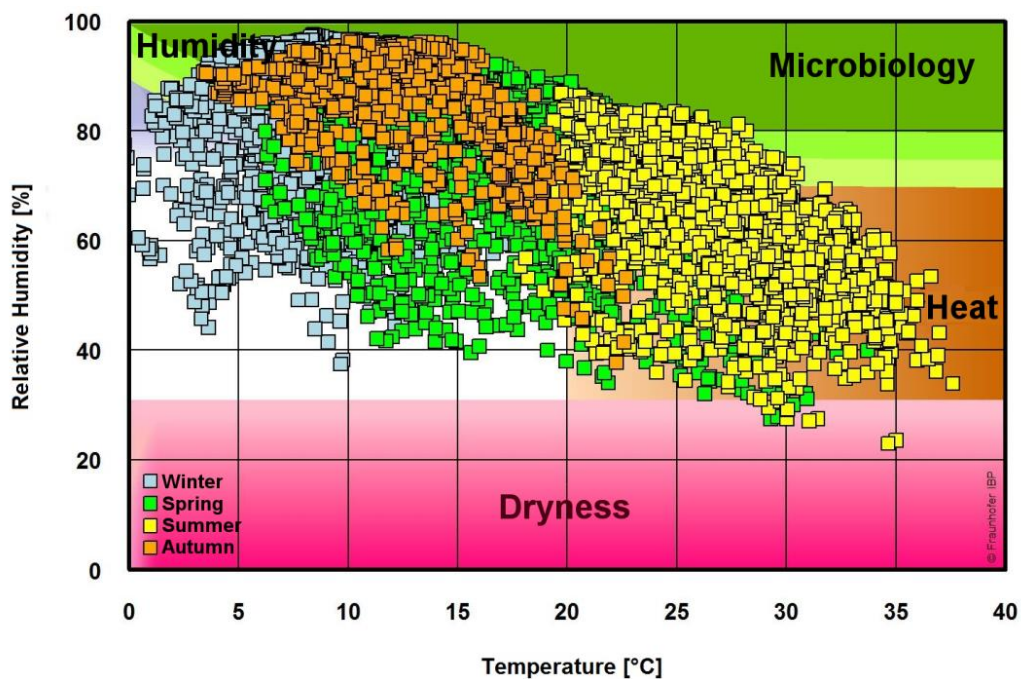


Figure 61:
Scatterplot of the climate at tomb 9 ES P4 P11 in the gap between protective glass and tomb. The graphs show the hourly mean of 10 minutes interval measured data, from 14.11.2014 until 08.09.2015.

Table 12:
Statistic data of relative humidity, temperature, and absolute humidity of the reference outside climate OS 31 P3, compared to measurement point 9 ES P4 P11 in the gap between protective glass and tomb, from 14.11.2014 until 08.09.2015.

9ES_front_P4_P11	Maximum	Minimum	Fluctuation Range
30d moving average T	28.9	7.9	21.0
30d moving average rH	85.9	59.6	26.3
30d moving average aH	18.2	6.6	11.6
30d moving average T outside	28.3	7.9	20.4
30d moving average rH outside	85.9	63.1	22.8
30d moving average aH outside	18.8	6.5	12.3
moving 24h fluctuation rH			55.0
24h fluctuation rH			55.0

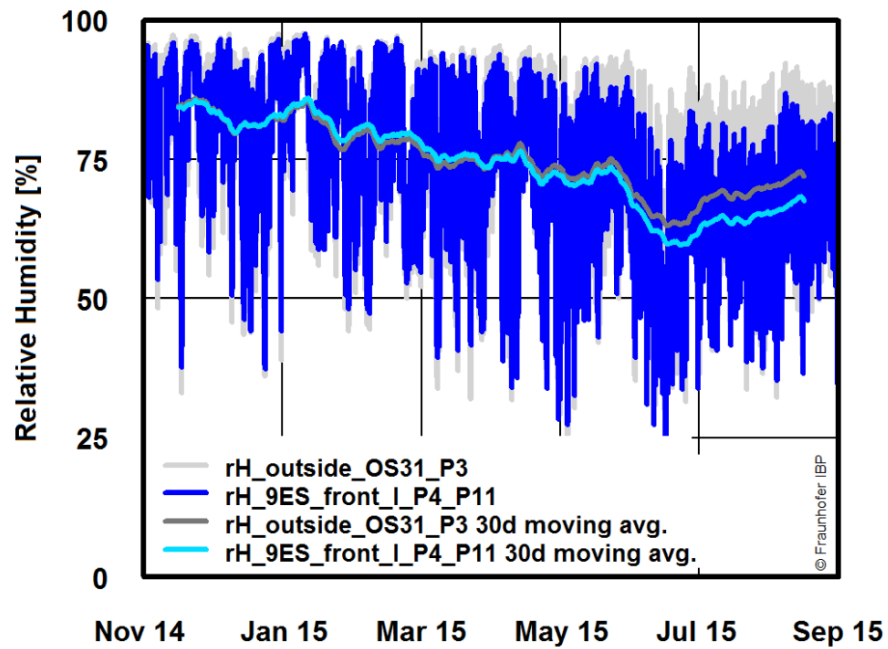


Figure 62:
Comparison of relative humidity of the climate at tomb 9 ES P4 P11 in the gap between protective glass and tomb with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 14.11.2014 until 08.09.2015.

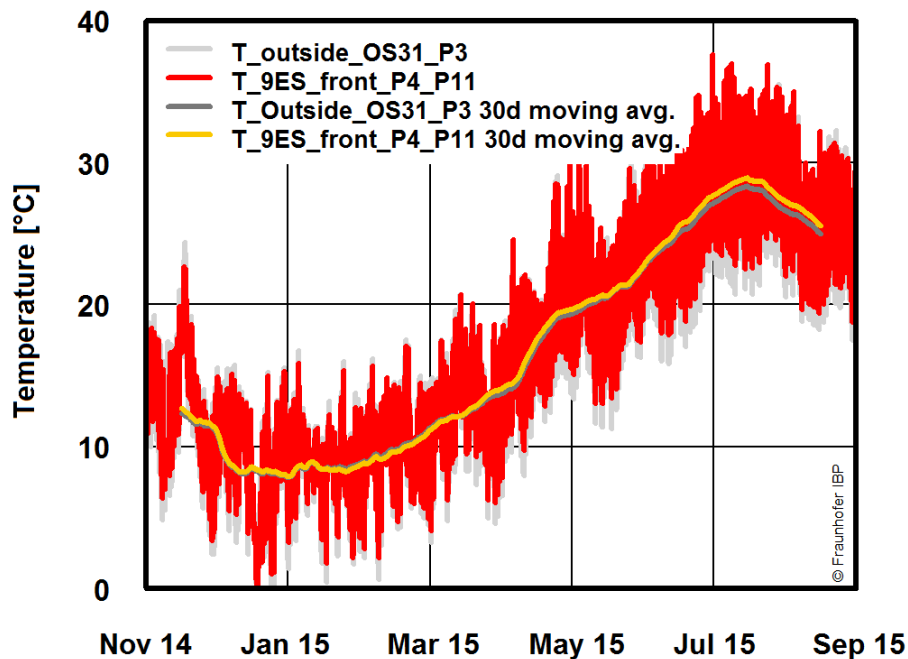


Figure 63:
Comparison of air temperature at tomb 9 ES P4 P11 in the gap between protective glass and tomb with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 14.11.2014 until 08.09.2015.

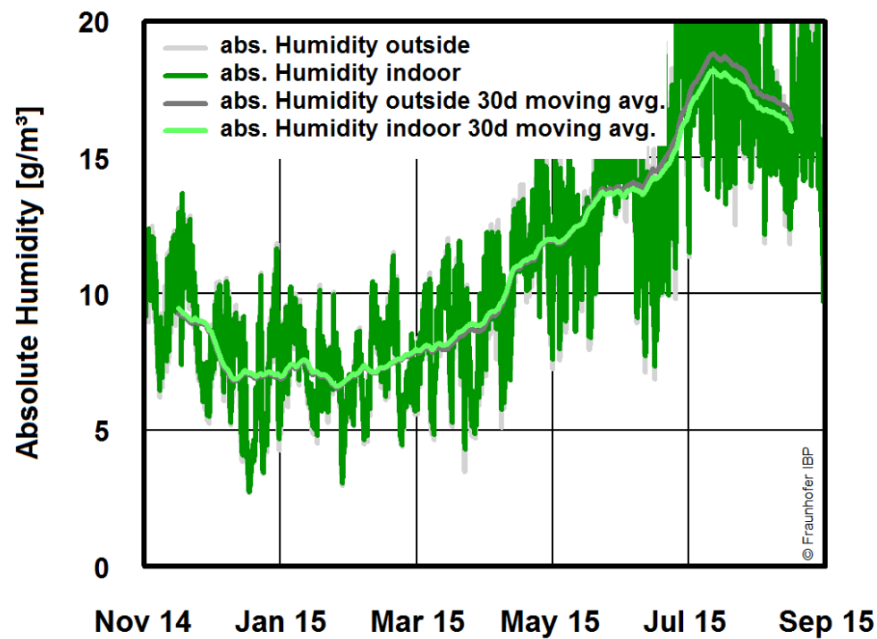


Figure 64:
Comparison of absolute humidity at tomb 9 ES P4 P11 in the gap between protective glass and tomb with reference outside climate OS 31 P3. The graphs show the hourly mean of 10 minutes interval measured data, from 14.11.2014 until 08.09.2015.

2.2.5 ES 9, Measuring Point 4, 11 compared to Measuring Point 5

The climate measurement on the front of the tomb on a cornice behind the protective glass is compared to the climate on the opposite side of the wall, on the back side. The wall is additionally protected by a roof, supported by a scaffold; see Figure 4, Figure 6 and Figure 7. Measurement Point 4 and 11 are still situated on the same place, only the data logger was changed.

Figure 65 to Figure 69 show the climate and basic statics of local climate ES 9 P4 P11 in comparison to ES 9 P5.

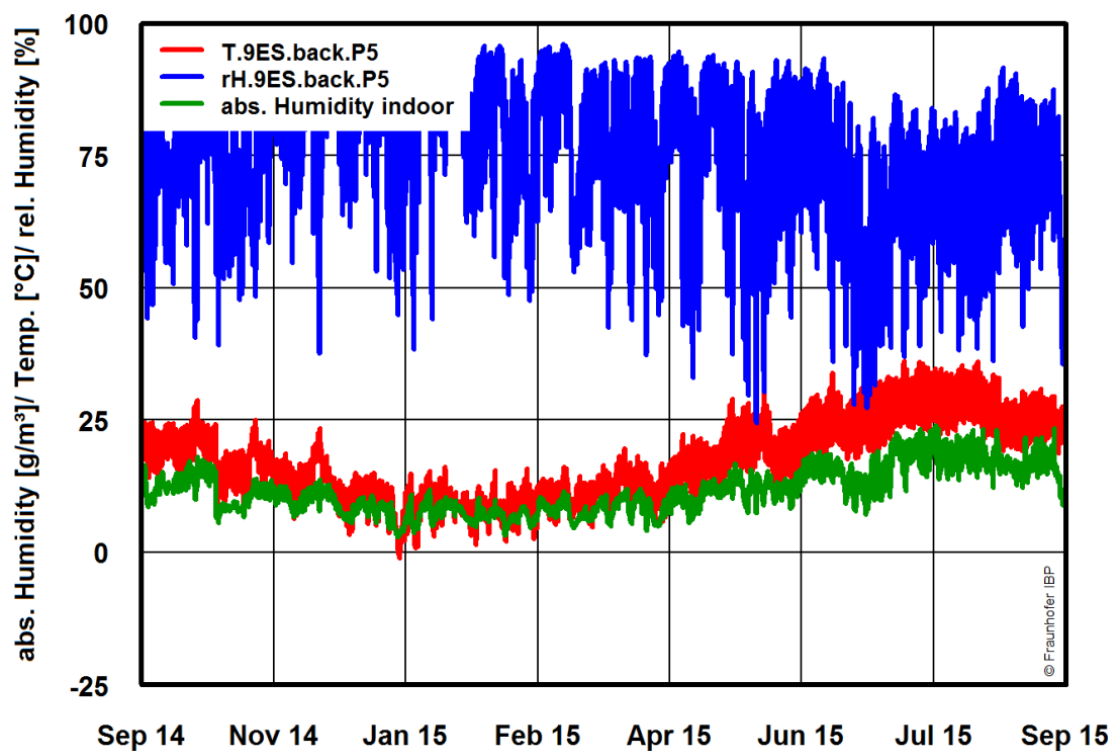


Figure 65:

Overview of the climate at tomb ES 9 P5 on the back side of the front wall. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Table 13:

Statistic data of the climate at tomb ES 9 P5 on the back side of the front wall, from 24.09.2014 until 08.09.2015.

Indoor Climate	Mean	SD	Minimum	P5	Median	P95	Maximum	Number
Relative Humidity [%]	75.6	14.2	24.3	49.4	77.5	94.3	97.1	8387
Temperature [°C]	17.1	7.5	-1.2	6.2	16.4	30.0	36.1	8387
Absolute Humidity [g/m³]	11.4	4.3	2.8	5.5	10.8	19.3	24.0	8387

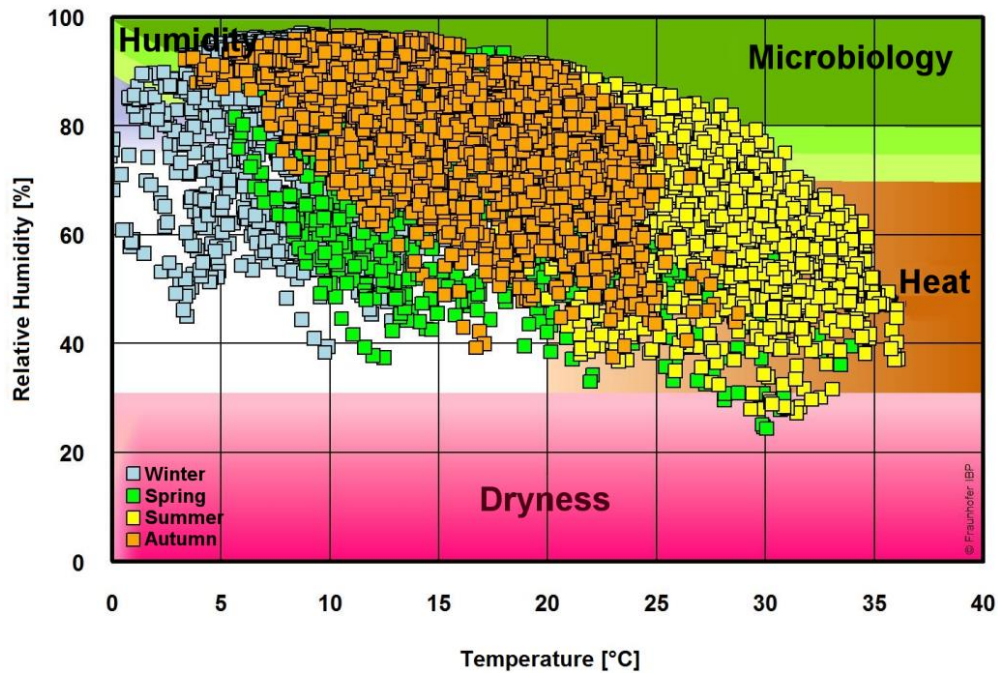


Figure 66:
Scatterplot of the climate at tomb ES 9 P5 on the back side of the front wall.
The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

Table 14:
Statistic data of relative humidity, temperature, and absolute humidity of the reference outside climate OS 31 P3, compared to measurement point ES 9 P5 on the back side of the front wall, from 24.09.2014 until 08.09.2015.

9ES_front_P4_P11_back_P5	Maximum	Minimum	Fluctuation Range
30d moving average T	28.7	8.1	20.6
30d moving average rH	86.2	61.9	24.3
30d moving average aH	18.7	6.7	12.0
30d moving average T outside	28.9	7.9	21.0
30d moving average rH outside	88.6	59.6	29.0
30d moving average aH outside	18.2	6.6	11.6
moving 24h fluctuation rH			58.7
24h fluctuation rH			58.7

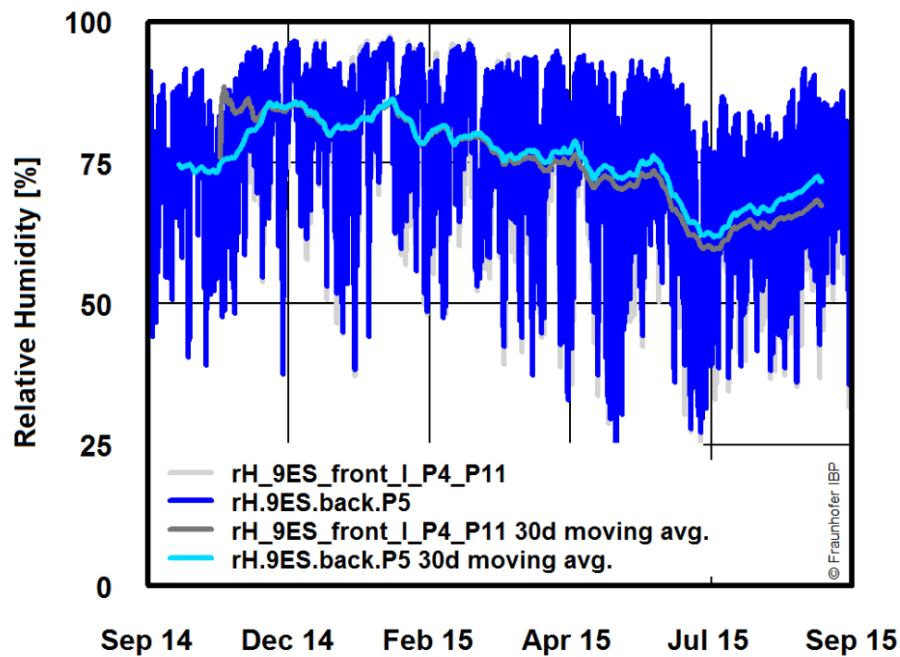


Figure 67:
Comparison of relative humidity of the climate at tomb ES 9 P5 on the back side of the front wall and 9 ES P4 P11 in the gap between protective glass on the front side. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

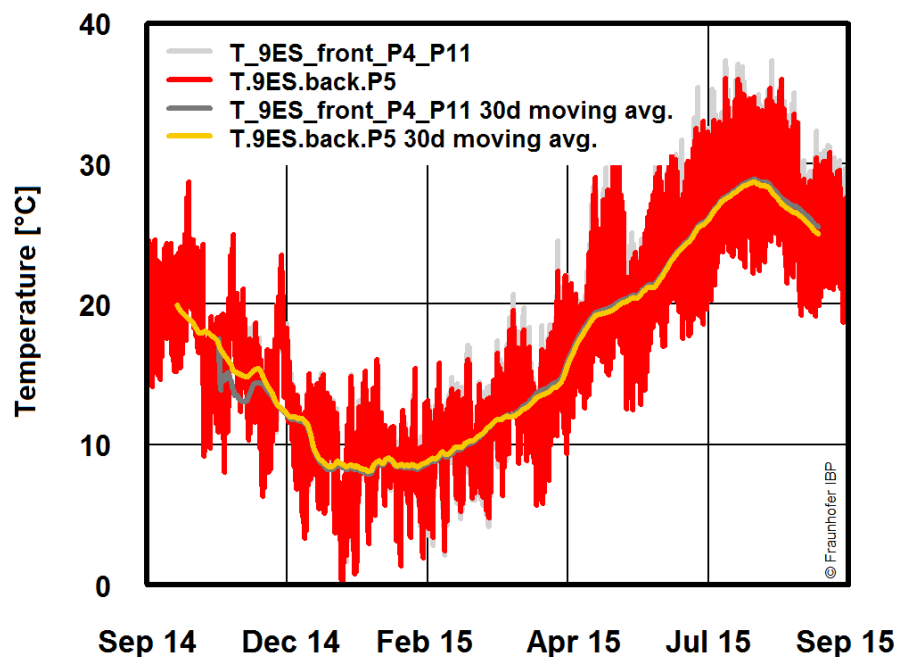


Figure 68:
Comparison of air temperature at the climate at tomb ES 9 P5 on the back side of the front wall and 9 ES P4 P11 in the gap between protective glass on the front side. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

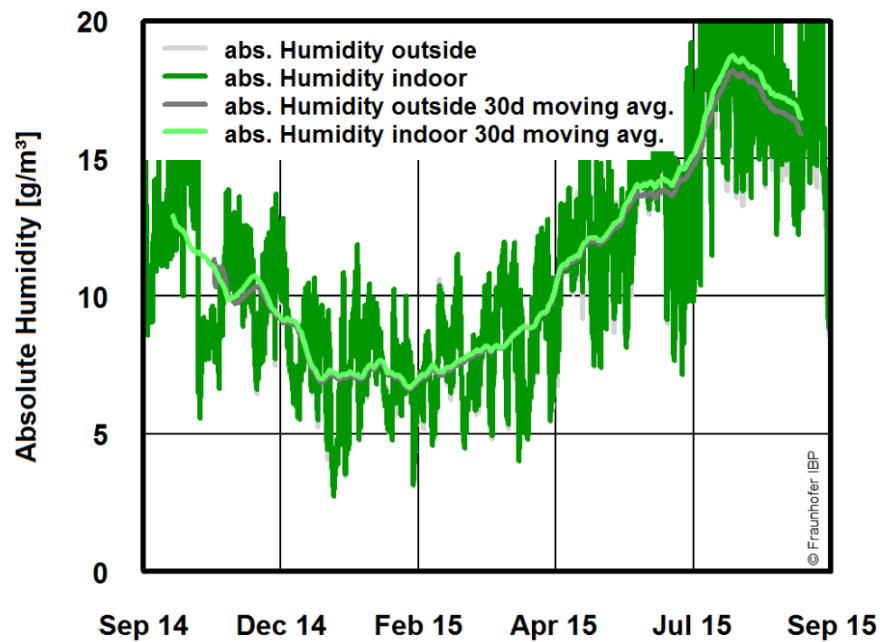


Figure 69:
Comparison of absolute humidity at the climate at tomb ES 9 P5 on the back side of the front wall and 9 ES P4 P11 in the gap between protective glass on the front side. The graphs show the hourly mean of 10 minutes interval measured data, from 24.09.2014 until 08.09.2015.

3 Conclusion and Outlook

The climate measurement at the tombs of Necropolis Porta Nocera shows different microclimates. All local climates are more or less outside climates. The comparison of the two measuring points, which are only slightly influenced by the surrounding and therefore comparable outside climates, at tomb OS 31 at the western end and at tomb D-N at the eastern end of the Necropolis, show a slight difference in temperature course. The difference in absolute humidity is within the range of uncertainty of measurement.

The tomb D-N has a protective roof, protective glass and a small cave. The microclimates differ considerable in temperature and relative humidity but also for the absolute humidity in the cave. In the cave the microclimate is much more stable showing less daily fluctuations and behaves like in an unheated indoor room. The absolute humidity in the cave is in average 0.6 g/m^3 higher compared to the local outside climate on top of the tomb. This is due to water evaporating from the tomb and soil to the air of the cave.

On the south wall of the tomb with protective glass a broad stripe of damaged i.e. almost vanished plaster is obvious. The damage mechanism is assumed as a combination of rising moisture from the soil, huge temperature and relative humidity fluctuations in conjunction with crossing salt deliquescence limits.

The horizon of the drying front is assumed at the area of the damaged plaster. With rising water salts may migrate. High ranges of relative humidity fluctuations can cause salt efflorescence by crossing deliquescence limits of salts. It is yet unknown which kind of salts are present or whether they play an important role at all. The high fluctuation of temperature may also cause thermal stress in the plaster.

To lower the thermal stress on the plaster by reducing the high fluctuation ranges a complete shadowing of the tomb, i.e. south façade would be necessary.

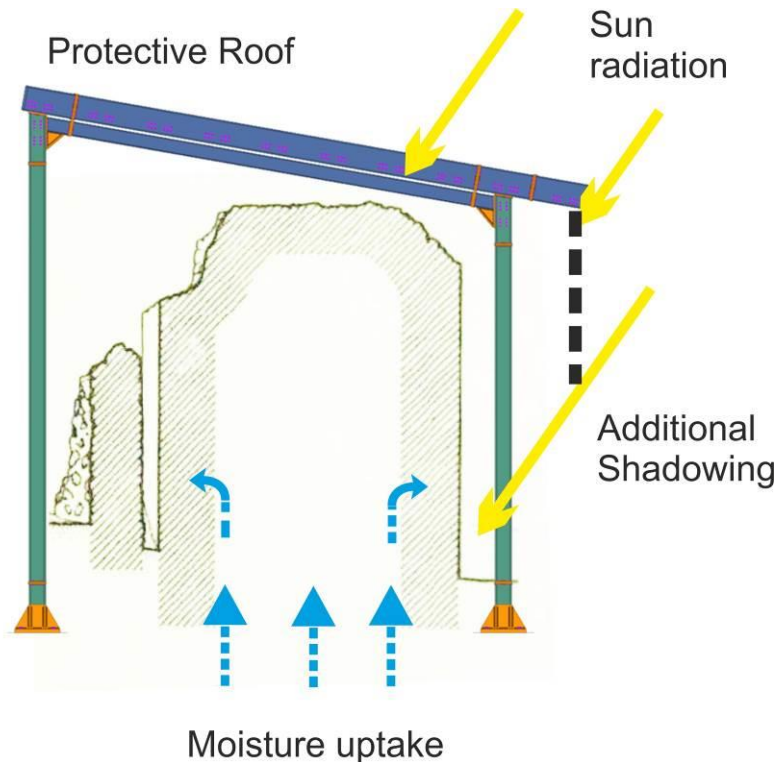


Figure 70:
Sketch of the effects of raising water and sun radiation on a tomb with improved shadowing by a protective roof.

The first measurements show only a small influence of the protective glass to the surface temperature. Additionally there is lower damage underneath the protective glass on the east façade of the tomb. To understand the effect of the protective glass in detail a second measurement campaign of local climates and surface temperatures is necessary.

4 Literature

[1] Antonio d' Ambrosio e Stefano de Caro: La Necropoli di Porta Nocera Campagna di Scavo 1983, in: Römische Gräberstraßen: Selbstdarstellung, Status, Standard: Kolloquium in München vom 28. bis 30. Oktober 1985. Hesber & Zanker (Ed.), Verlag der Bayerischen Akademie der Wissenschaften, Munich 1987, p199-228.

[2] IBAM Institute for Archaeological and Monumental Heritage of the National Research Council Italy, PSPP Porta Nocera Necropolis Preliminary Campaign, 22nd September to 14th November 2014.