Monitoring the Hygrothermal Performance of Strawbale Walls

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1 Introduction

Straw, as a fiber, has been used as part of building materials for several thousand years. With the invention of the mechanical baler in the early 1900's it became possible for compressed straw to be used as the primary building block of exterior building walls. Although strawbale (SB) houses were popular for a short while in a local area of Nebraska, they lost favour for nearly half a century. There has recently been a rebirth in SB house construction and interest. In many cases the interest stems from the highly insulating, simple, and sustainable nature of SB walls.

Although there is a large and growing body of empirical evidence that strawbale buildings can be used very successfully, the scientific justification and explanation is lacking, and hence accepted engineering approaches to design, testing, and inspection have not been well developed.

To support the growing volume of rice straw agricultural waste the State of California supported a research program to improve the level of scientific knowledge of strawbale wall behavior and performance. A California winery, interested in quality buildings and sustainable action, commissioned the construction of a large strawbale building to be used as a tasting room, barrel storage room, and tank farm on a site adjoining one of their vineyards. They offered access to this unique building for a comprehensive enclosure wall monitoring program.

The report describes the approach, equipment, results, and implications.

2 Monitoring set-up

The building is U-shaped in plan, with the open end of the U facing North. The outward-facing walls of the West, East and South side have large overhangs (Figure 2.1) whereas the other walls have planned future extensions so began the monitoring period with almost no overhang.

The Barrel Room is specially conditioned to maintain temperatures of about 60 F and 80%TH. This are quite different than the conditions desired for normal occupancy. Hence, this project allows us to inspect the effect of two different interior conditions as well. A public bathroom is included, in the monitoring program, as is a tasting room and utility room.

A total of 13 locations of interest (called stacks) within the building walls were chosen (Figure 2.2). These are listed in Table 2.1. Most of these locations were exterior walls, but some divided the different indoor environments. At each location, temperature and relative humidity were usually measured at upper, lower, and middle location over the height of the wall, and at interior, exterior, and middle of the wall thickness (Figure 2.3). Hence, as many as nine sensors were installed to form a stack. The custom-built sensors used (Figure 2.4) are quite small, have good accuracy (±0.2 C, ±2%RH), and are reasonably priced.

Figure 2.1: View of south-west corner at entrance door

Interior conditions were measured in the barrel room and the tasting room. A full exterior weather station (Figure 2.5) measured temperature, RH, wind speed, wind direction, solar radiation, and rainfall.

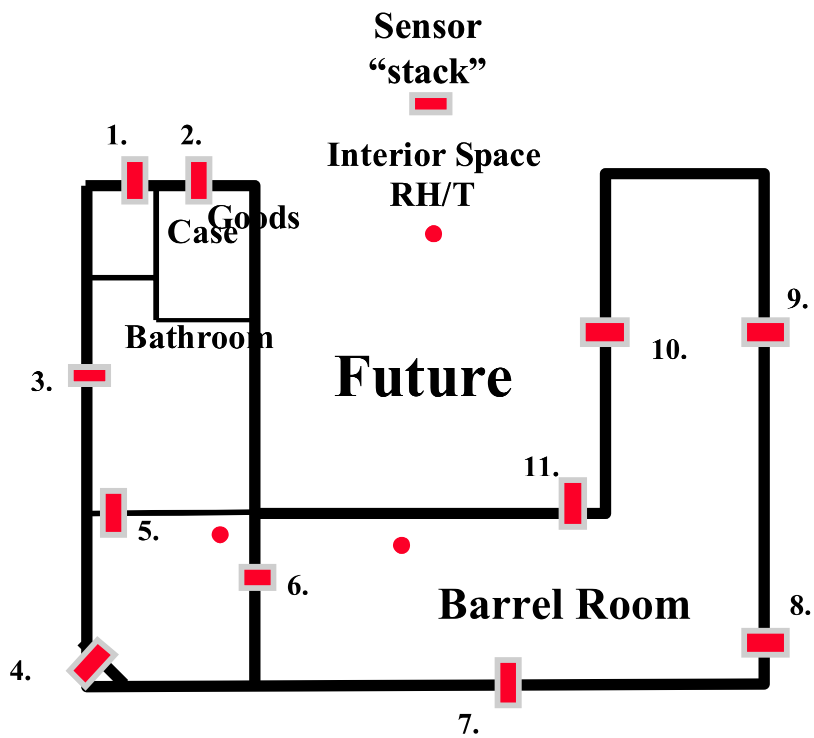


Figure 2.2: Location of sensor stacks

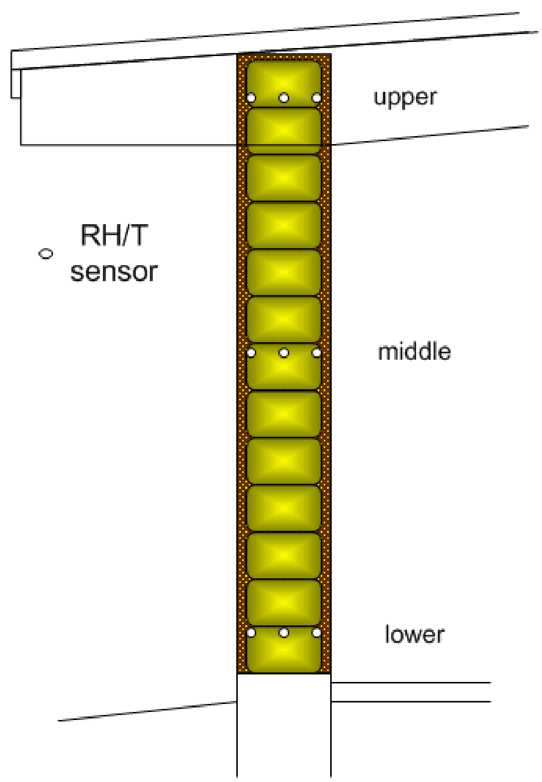


Figure 2.3: Sensor locations per stack

Table 2.1: RH and temperature sensor locations

Location Identifier	Near Gridline	Description	Orientation	Number	Comments
1	H-1	Utility Room	N	4	Compare with location #2/ triangulate
2	H-1.6	Case Goods	N	7	3 middle, int. and ext. on to & bottom
3	C-1	Bathroom exterior	W	7	Same as 2, mid height ones at sill
4	A-1.2	Entrance	SW	3	Thick wall, over header, inside and out
5	B-1.2	Bath-Tasting	Interior	3	Small temperature gradients means little vertical stratification
6	A.1-5	Tasting-Barrel	Interior	3	Small temperature gradients means little vertical stratification
7	A6	Barrel Room	S	9	Critical wall and exposure
8	A.1-13	Barrel Room	E	9	East barrel room exposure
9	F-13	Barrel Room	E	4	Wall location near mechanical equipment
10	E-12	Exhaust Duct	W	3	Near exhaust, triangulated
11	H-12	Barrel Room	N	9	Lowest 3 in straw clay
12	H-12.3	Inlet Duct	N	3	Near intake
13	B-12	Barrel Room	N	3	3 @ hoseport, 1 in mid box + 2 extra T sensors, 1 near top
14		Barrel Room		1	Interior T/RH
15		Tasting Room		1	Interior T/RH
16		Outdoors			Exterior T/RH, wind, sun

All wiring from the sensors was run back to two data acquisition systems, one in the Low Voltage Room and the other in the Barrel Room. One of these systems can be see in Figure 2.6.

The sensors were installed by the contractor (Vital Systems) during the construction of the walls. The data acquisition system was installed at the end of May, and data began to be collected May 31, 2002. Interior finishing and windows were still being installed in the building at this time, although the Barrel Room was being conditioned at this time.

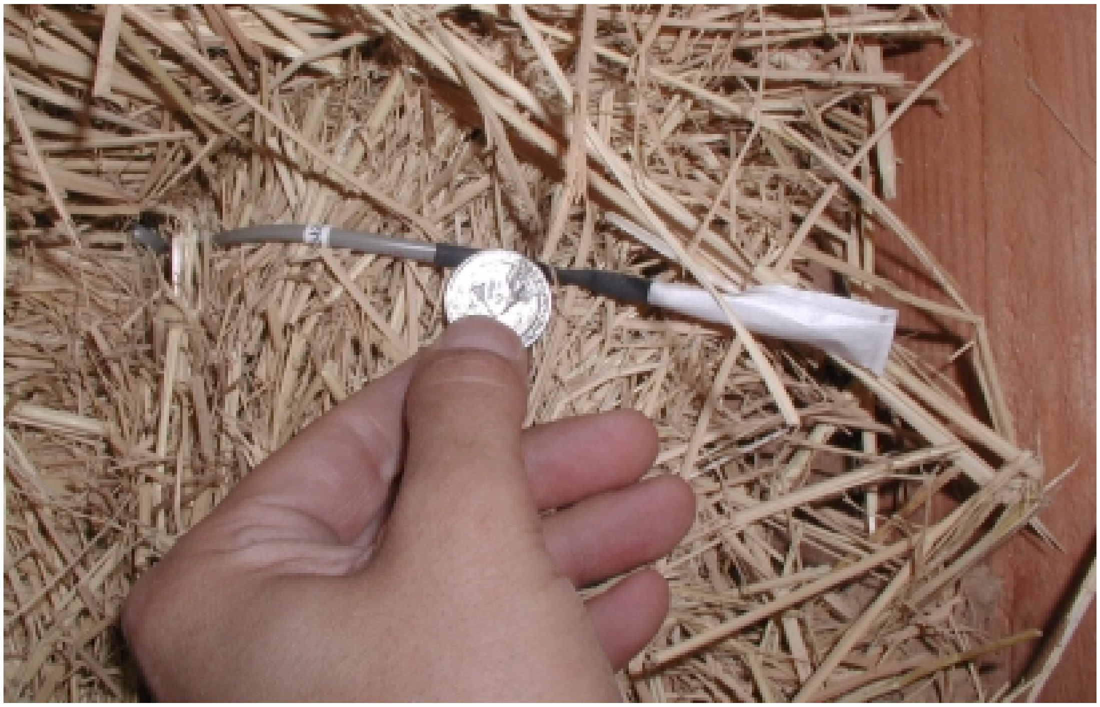


Figure 2.4: Relative humidity and temperature sensor installed in SB

Figure 2.5: Weather station on house adjacent to winery

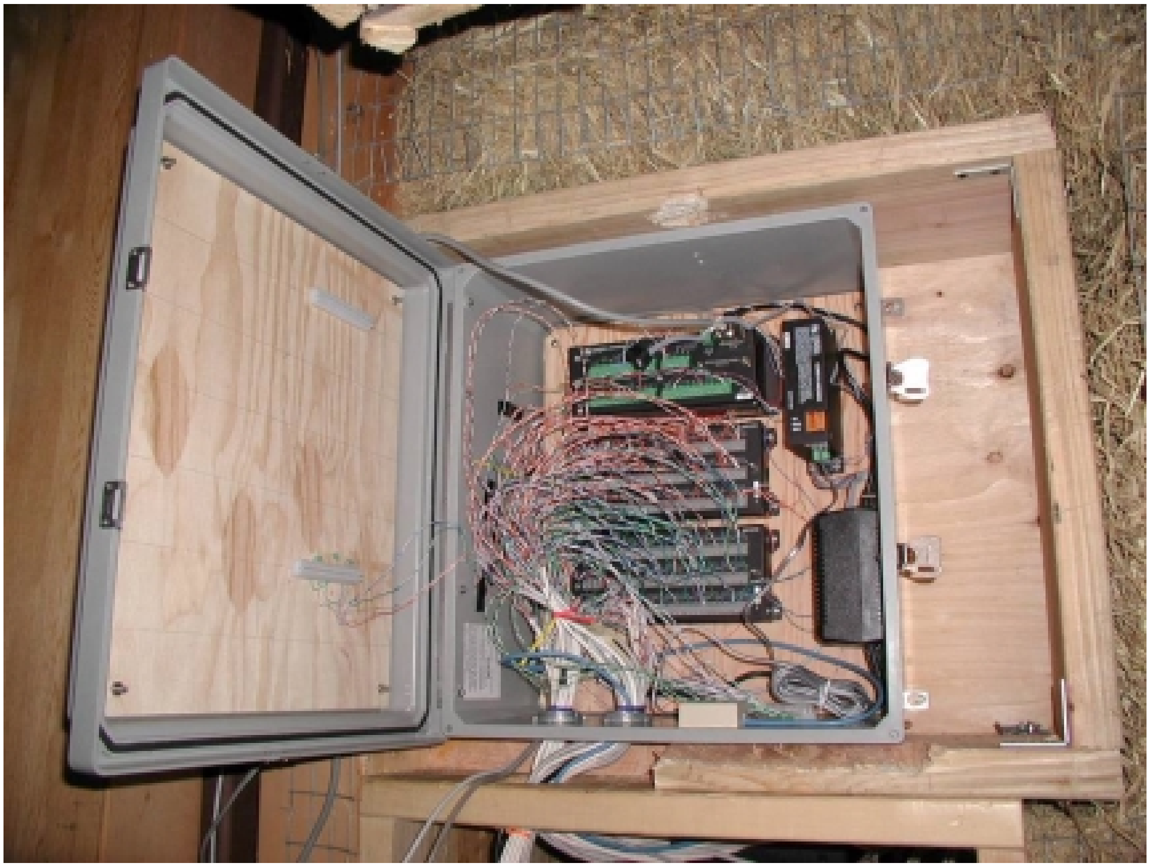


Figure 2.6: Barrel Room Data Acquisition System

This report examines the data over the period June 1, 2002 to July 5, 2003, a period of 400 days. About 200 hours of data (of a possible 9500 hrs, for 97.5% coverage) was lost in the barrel room and 600 hours in the low voltage room due to power outages or disrupted telephone access to the site. Site 11 was never connected, as the wires could not be found.

3 Results

The results are plotted for the entire study period in the Appendix for each of the sites, as well as the exterior and interior conditions. Temperature and humidity are plotted on the same graph.

Several of the sites are examined below in more detail on different time scales to explain certain aspects of performance more clearly.

3.1 Nomenclature

A set of sensor codes was developed to organize the sensor function and location. This code is comprised of 4 characters, defined below:

- Sensor stack #: 1 through 16
- Height: M-Middle, U-Upper, L-Lower
- Depth: E-Exterior, N-iNterstial, I-Interior
- Function: H-Humidity, T-Temperature

For example, a sensor labeled 8MEH is located at stack site # 8 (East Wall of Barrel room near south corner) at midheight near the exterior (just behind the earth plaster) and measures humidity.

3.1.1 Site 8: East Wall of Barrel Room

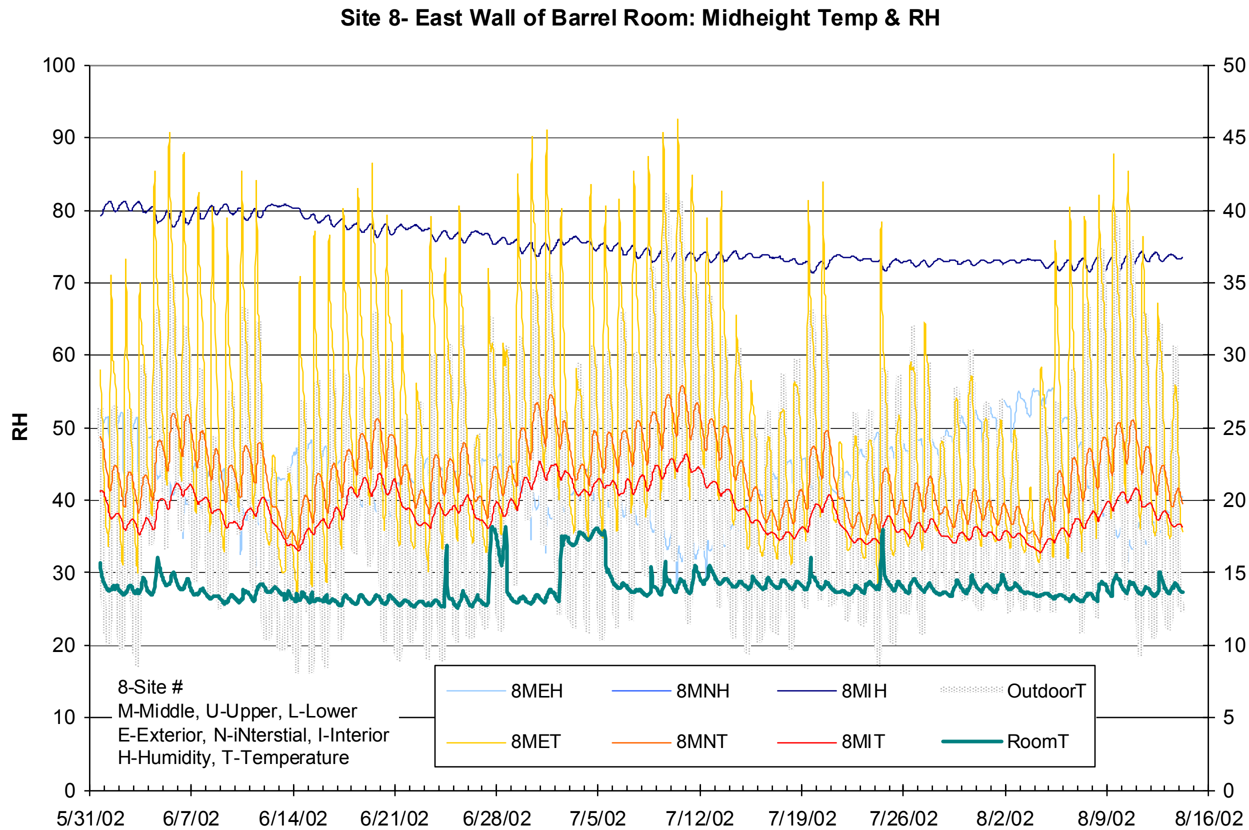


Figure 3.1: RH and T within Site 8, East Wall of Barrel Room

The relative humidity is high near the inside surface, but dropped slowly over the period (likely construction moisture leaving) to around 75%RH over the period. The middle of the bale and the exterior RH are both low, around 45 to 55%RH.

More detail can be seen from the shorter time scale shown in the plot below (Figure 3.2). To indicate a sense of the time-density of the data, 8MNT was plotted with a small x at each data point. As can be seen, the smooth lines in most plots are created by a large number of closely spaced data points.

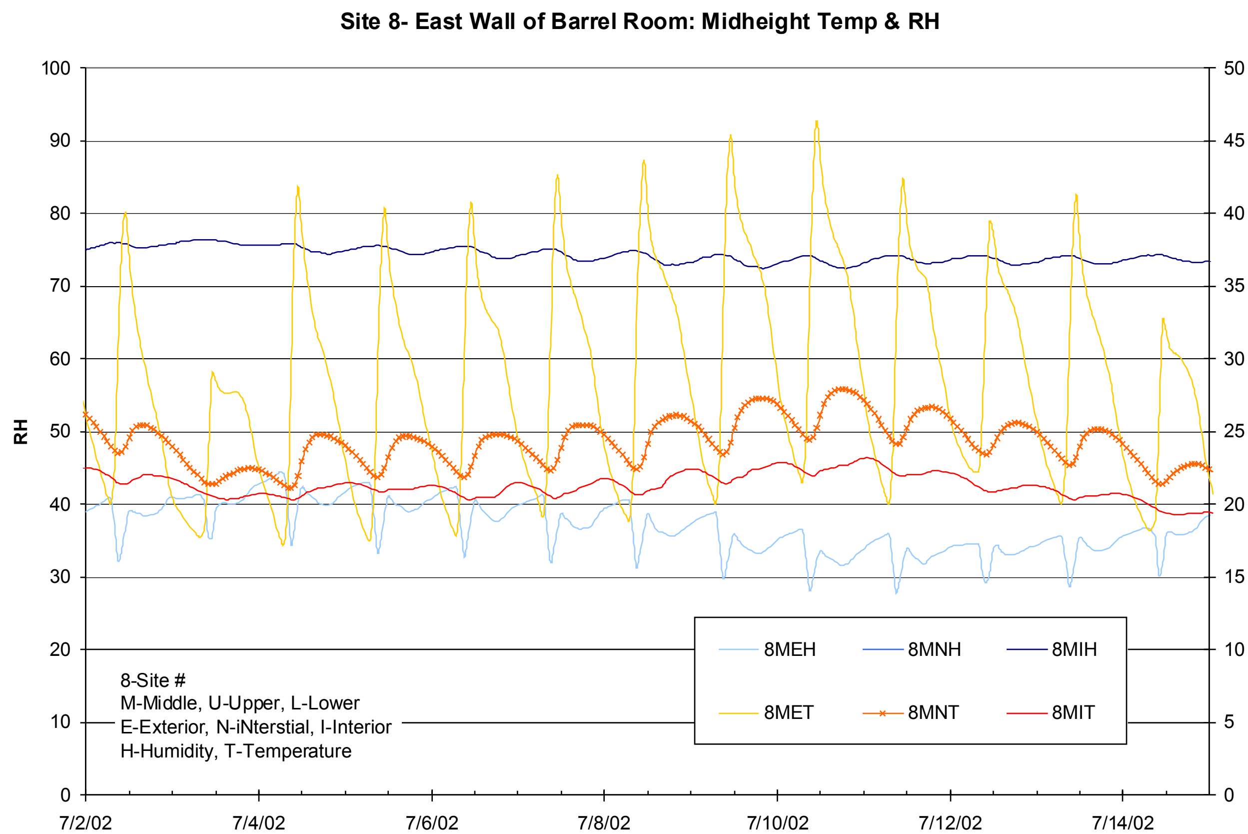


Figure 3.2: Detail View of Site 8

The temperature behind the exterior stucco of the wall (8MET = MiddleExteriorTemp) at mid-height often rises quickly in the morning, peaking at around 40 ºC at 11:00 am. This is clearly caused by the morning sun, which is shaded on this wall by noon. The exterior temperature peaks later in the day (4 or 5 pm) and is usually lower. The temperature at the interior plaster (MIT) is much cooler and more stable, hovering near 20 ºC (68 F) and varying by only about 3 ºC over the period. Daily variations of the interior plaster is only on the order of 1ºC. The middle-of-bale temperature tends to vary between 20 and 25 ºC. The wall remains above the exterior and interior temperatures because of solar exposure.

3.1.2 Site 7:South Wall of Barrel Room

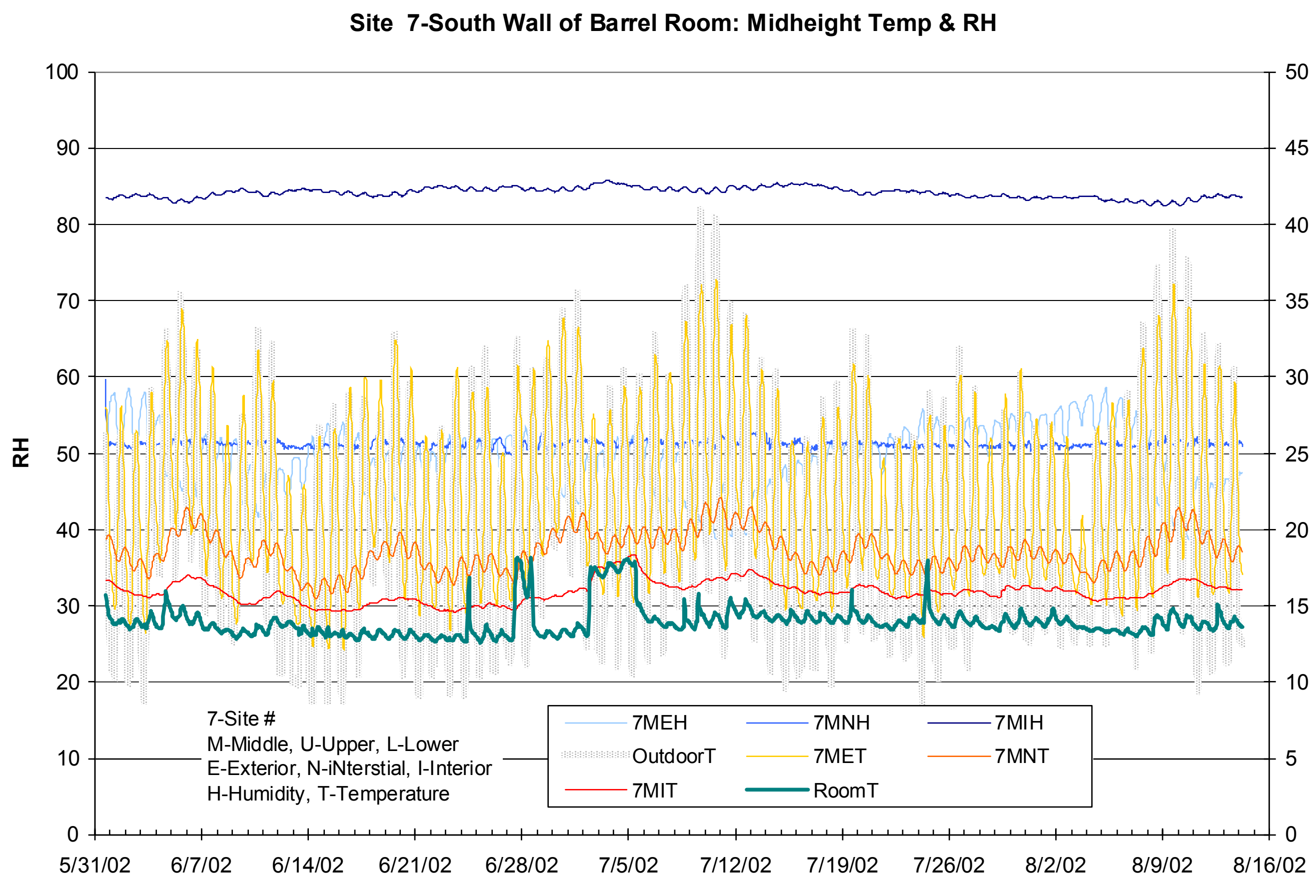


Figure 3.3: RH and T of South Wall of Barrel Room

The shading and high angle of the sun on the south side apparently avoids direct sun exposure on the exterior at mid height over this period since the 7MET (mid-height, exterior, temperature) sensor remains below the exterior temperature and peaks at a slightly later time (5 or 6 pm)(Figure 3.3). The exterior and mid-bale RH are slightly higher at this site than the east side but remain below 55%RH for the most part.

The cooler interior temperatures (they are more than 5 F cooler than the east side, likely because of the shelering effect of the barrels) however, resulted in a higher than desirable RH just behind the earth plaster of 85% over the period of this graph. The RH dropped during the winter, but the plot in the Appendix shows that the RH is rising again toward the end of the period. Since all three locations are showing the same response, this means that the interior RH of the barrel room should be reduced.

3.1.3 Site 6: Barrel Room to Tasting Room Wall

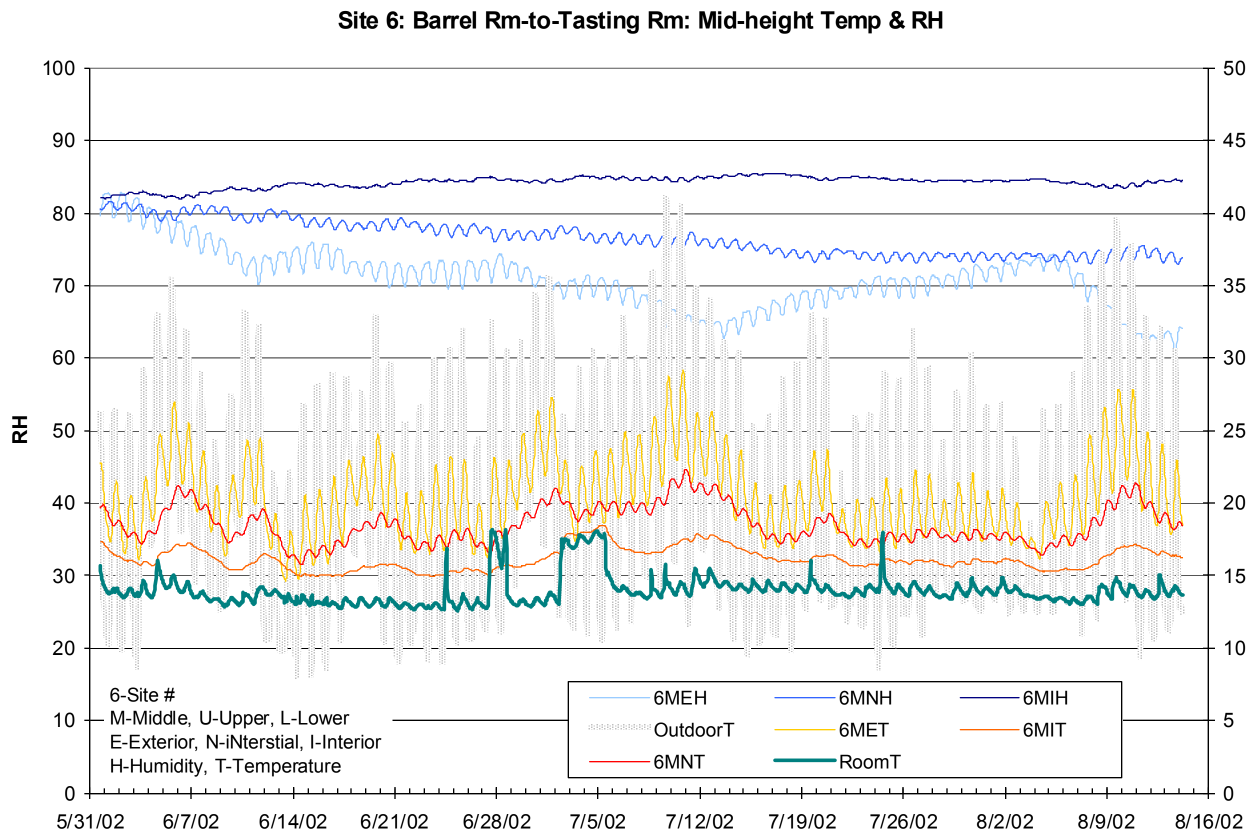


Figure 3.4: RH and T Within Wall Separating Tasting Rm and Barrel Rm

Site 6 (Figure 3.4) examines the unique wall that separates the barrel room from the tasting room. At the end of the study period, both sides are conditioned, whereas at the beginning of the period, the tasting room was a moderated version of outdoor temperature and humidity conditions. The outside temperatures are much lower than sensor stack Site 7 or 8 since the tasting room temperature is moderated. With no large driving temperature difference, the RH within the strawbale is predictably higher. In fact, it is over 85% just below the interior plaster, and around 70% near the tasting room side. Some drying of the tasting room plaster clearly occurred over the summer, but the tasting room side gains moisture as the barrel room RH increases.

As the tasting room was conditioned later in the year, and the barrel room RH was controlled, the RH in these walls dropped to safer levels, showing the drying of construction moisture (Figure 3.5). The barrel room side is clearly the side which has the highest RH, since this is the source of the moisture, and the temperature across the wall is uniform. It can also be seen how the temperature variation become much less later in the period as the building interior become conditioned.

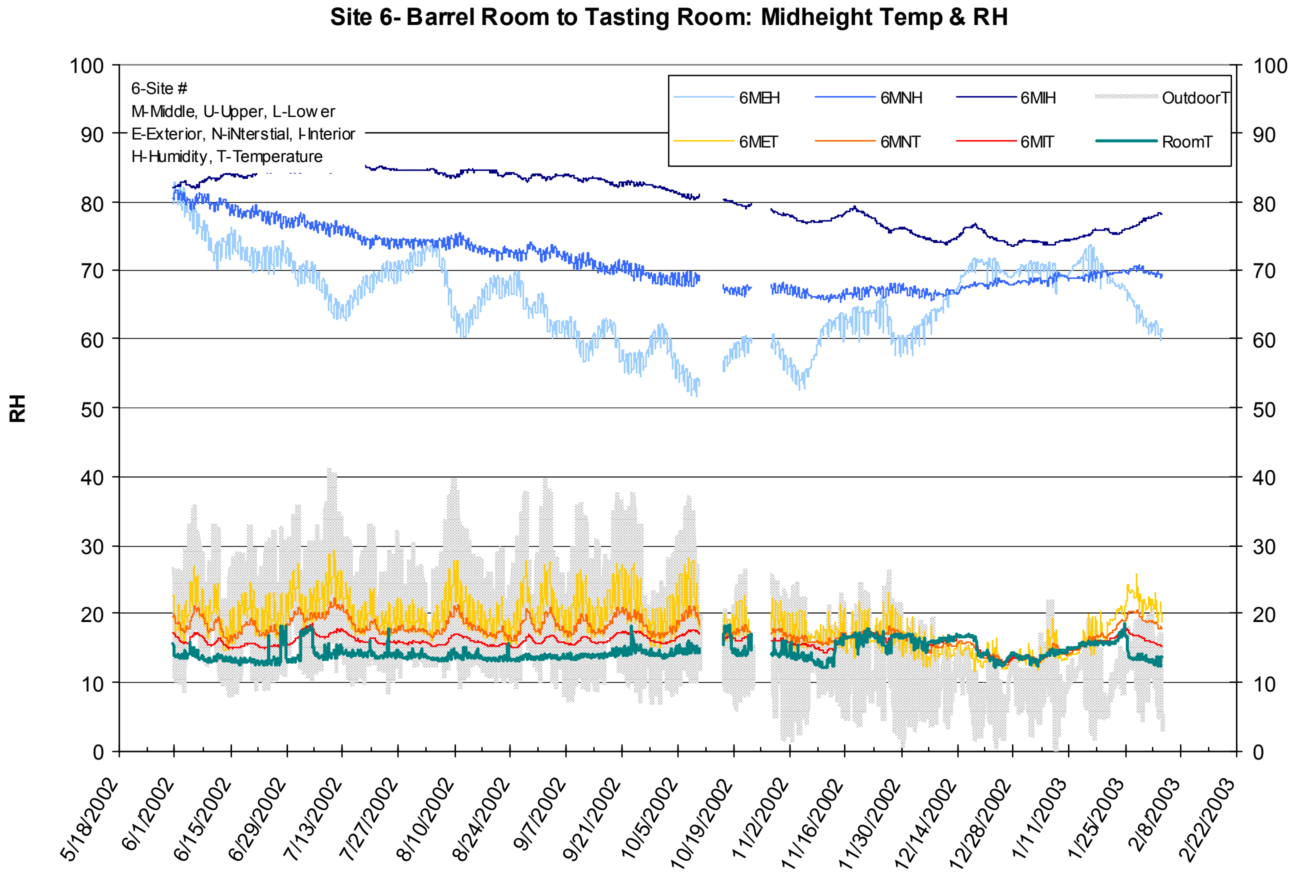


Figure 3.5: Drying out of Sensor Site #6

3.1.4 Height Variations

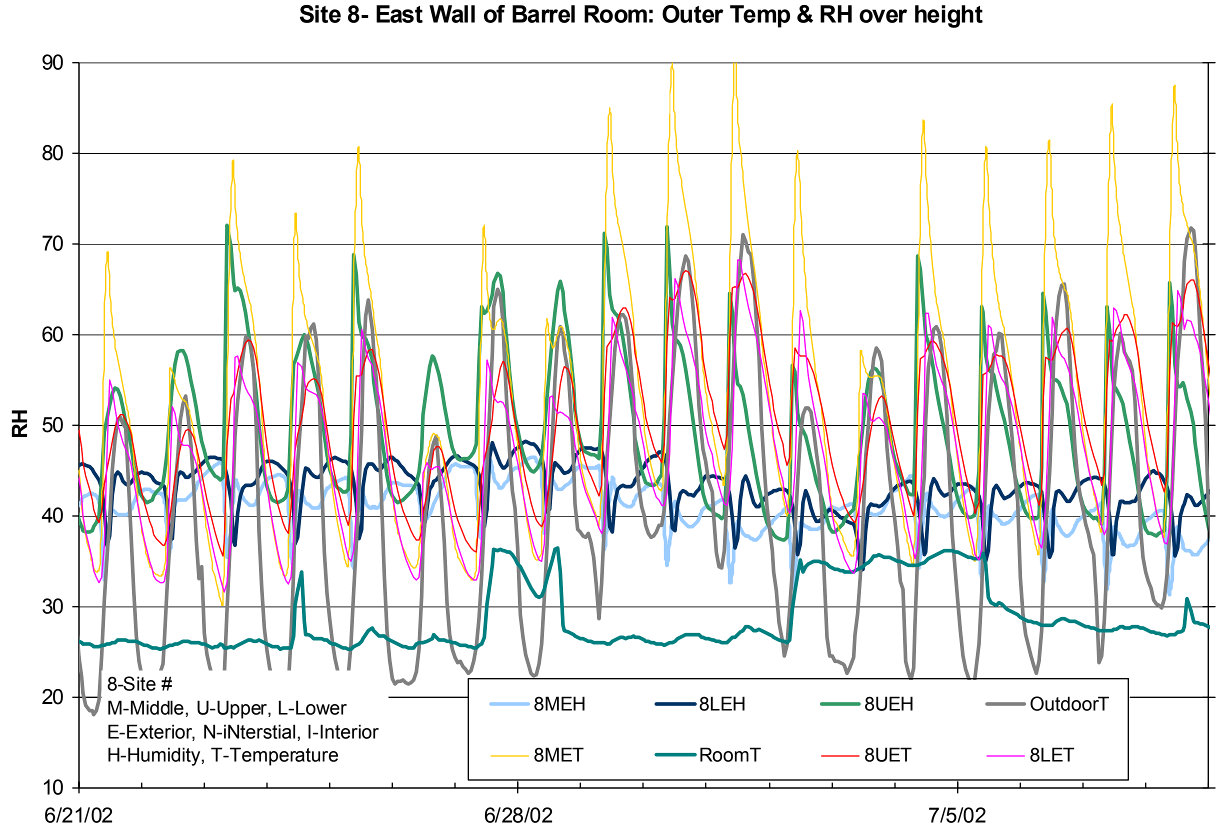


Figure 3.6: Vertical Variations in T and RH at Site 8

Variations over height were investigated in more detail at Site 8 (Figure 3.6, Figure 3.7).

The sensors UIT and MIT and UIH and MIH show that the upper and middle locations read very similar temperatures and RH. This provides some reassurance that the sensors agree with each other. The LIT sensor is somewhat cooler, likely reflecting the heat loss through the concrete slab near grade and the fact that cold air falls on the inside. The LIH sensor is assumed to be damaged since it is unnaturally stable.

Sensors MEH and LEH are almost identical, whereas UEH (the uppermost sensor) is much more variable.

The exterior temperature variation suggests that the mid-height sensor is the warmest while the top and bottom are cooler. The difference is mostly noticed in the peaks. This could be because the top sensor is more protected from the sun by the overhang, and the bottom sensor is connected to the massive and earth-connected concrete footing wall.

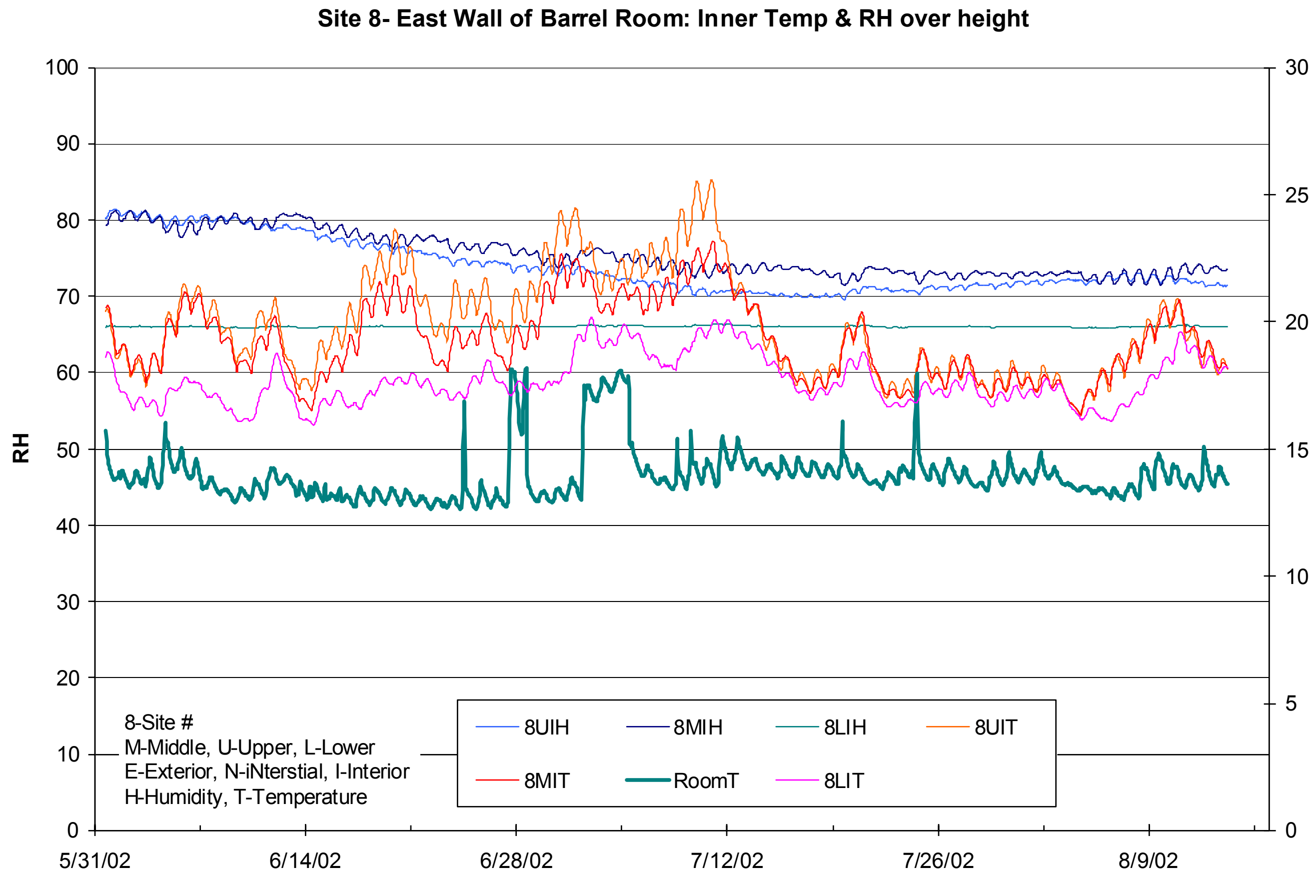


Figure 3.7: More variations of RH and T over height

3.1.5 Rain Response

The walls responded strongly to rain deposition. It is clear that even with the large overhangs some wetting does occur. An example of this performance can be seen at Site 7 (south wall of barrel room) just before Christmas, 2002 (Figure 3.8). The weather plots show heavy rain and winds from the south, and the wall on the south responds dramatically. The RH at the exterior rises quickly to almost 100%, and then drops to below 80% over the next 6 weeks, and returns to equilibrium within about 8 or 9 weeks. The interior RH sensor increased slightly, but almost not noticeably.

The lower sensor on the wall shows essentially the same performance, although the outer RH sensor failed in this case. The middle RH sensor shows that the wall does dry out. The upper sensor does not show this response pattern, since the overhang clearly protects this part of the wall from all rain. Note that all walls exhibit an increase in RH in the exterior sensors during the winter because of the dropping temperatures and increasing exterior RH.

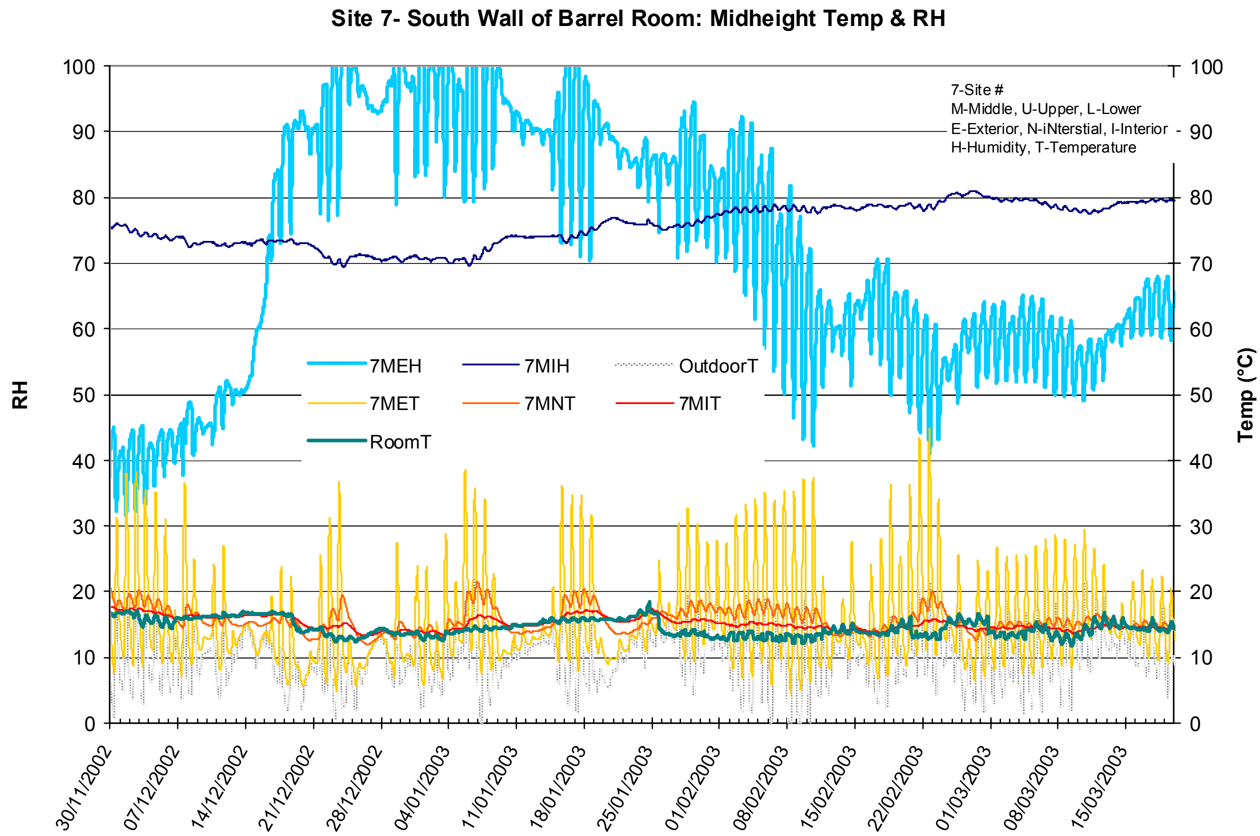


Figure 3.8: Response of Site 7 (midheight) to rain

Site 10 is an exhaust port on the north side of the barrel room. Wetting from a rain event in November dried quickly, but a second rain event in November slightly rewet the wall again. The wall has dried down, quickly, but shows how exterior moisture can redistribute to the center of the wall as part of the drying process.

Site 13, the hoseport, shows repeated wetting events during the winter months, and RH values of close to the threshold for much of the monitoring period. Whether this is due to rain collection around the penetration, condensation on the cold metal pipes, leakage from the pipes, or sprayed water from operational activities is uncertain, but the cause should be investigated on site by the building managers. It appears to be slightly drier and more stable over the last 4 months, although why this is the case is unknown.

4 Conclusions and Recommendations

The monitoring of the strawbale walls of the winery was very successful. Large amounts of detailed data was collected.

Temperatures vary rapidly over the day in the exterior layers of the SB, and where exposed to the sun, are dominated by solar effects. The sun can heat even the back of heavy earth plaster surfaces to 20 C (30 F) above outdoor air temperature. The temperatures behind the interior plaster are quite stable despite large excursions in exterior temperatures. The effect of shading can be important – the shading of walls during the second summer resulting in significantly lower surface temperatures.

The RH within the walls varied slowly in most cases, often changing slowly over weeks. This is due to the moisture storage capacity of the SB wall system. Short-term upward spikes occurred when walls were exposed to rain. Rain control for earth plastered strawbale buildings is clearly essential. Rain causes the greatest and quickest increase in RH. Drying can occur quickly after rain events if conditions allow it, but serious wetting will often require at least 4 to 8 weeks to dry.

The second most important moisture load is relative humidity. In the case of the barrel room, the high interior RH places the walls at high stress. Because of the monitoring, it is known that the wall RH is being maintained, just, within the safety levels. (In most buildings, interior RH of much less than 50%RH should be maintained when it is cool outside, and even lower when it is cold outside.) In the case of the subject building, careful monitoring and control should be used to keep the RH in the Barrel Room at or below a daily average of 80% RH, since the south wall is exhibiting slightly high readings.

The hoseport (site 13) showed the consistently highest readings over the winter, but now appears to be drier and more stable. It should be inspected by the building operators.

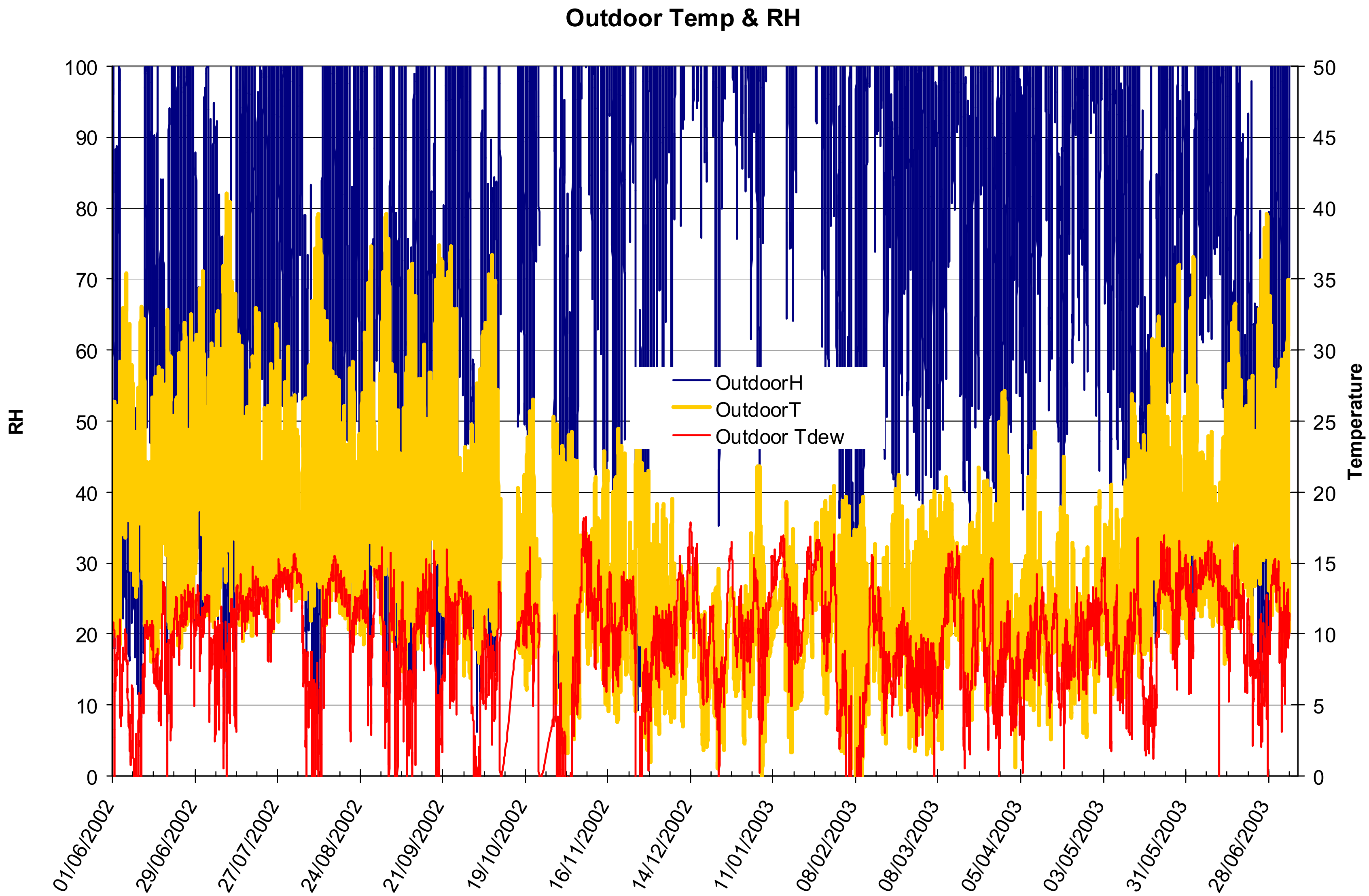
Appendix A:

Temperature and RH plots for all sites for June 1, 2002 to June 30, 2003

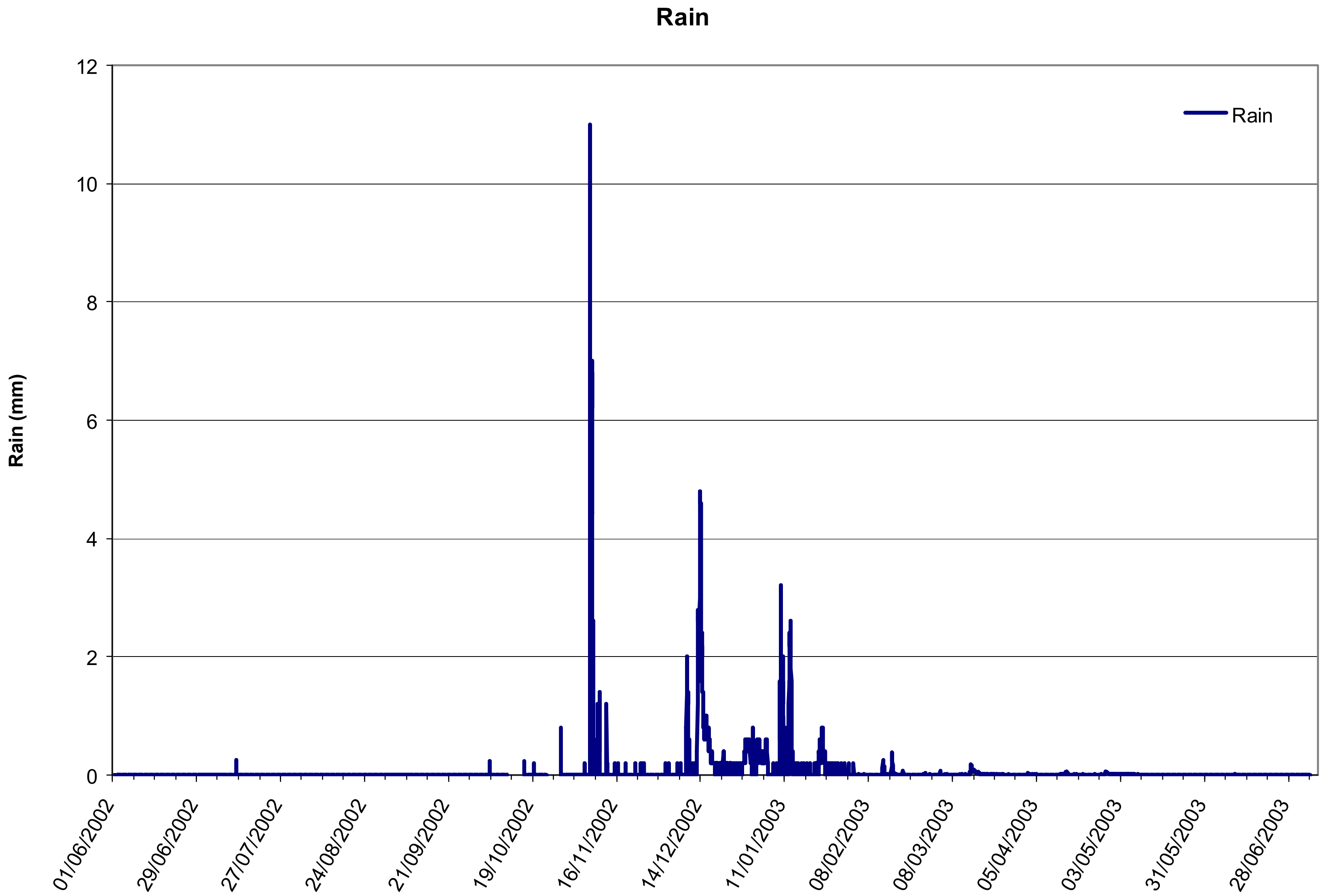
Approximately 9000 hourly average reading for each sensor.

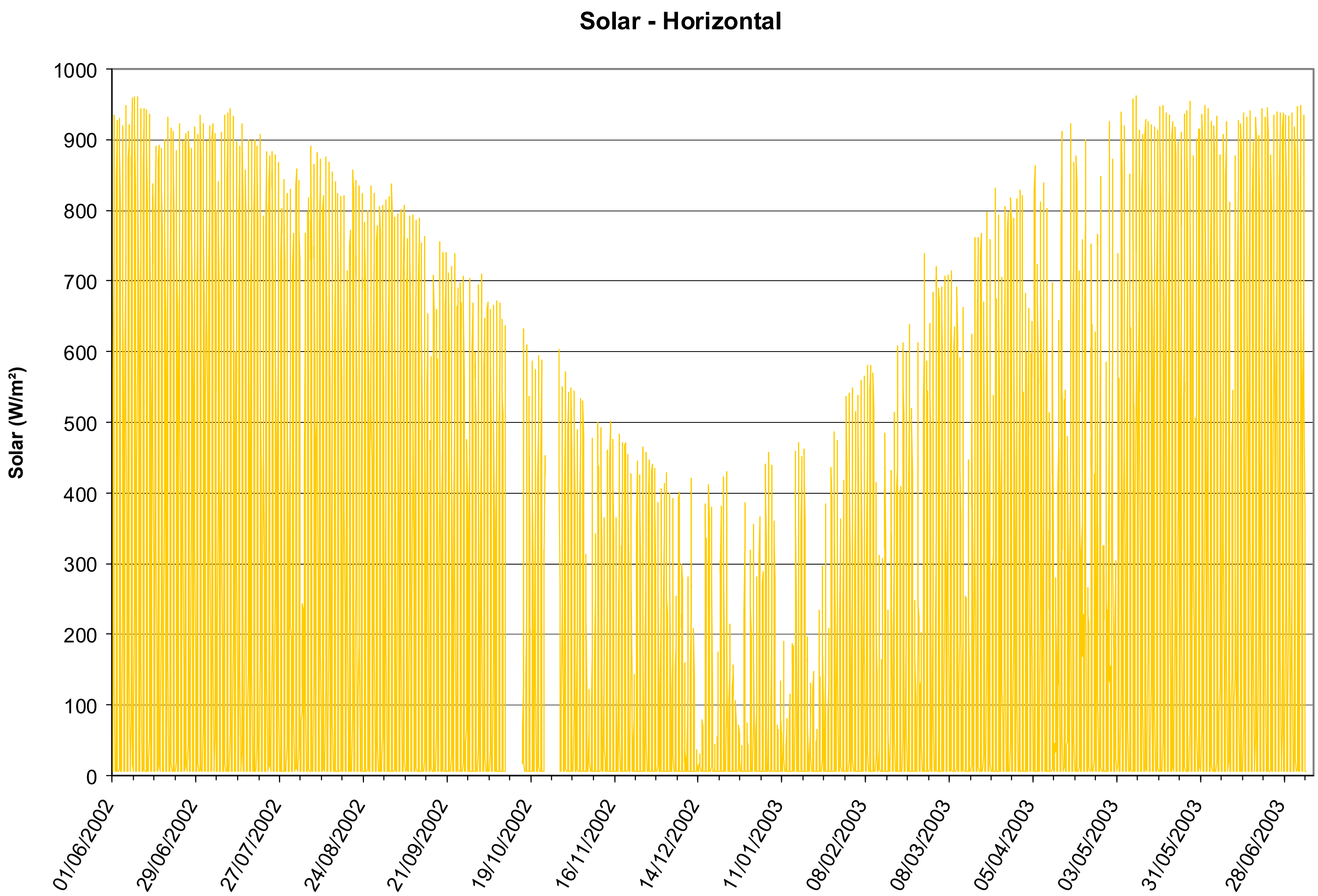
Note: Site 11 was never wired up.

Celsius	Fahrenheit
0	32
5	41
10	50
15	59
20	68
25	77
30	86



Outdoor Temp & RH
RH
Temperature
OutdoorH
OutdoorT
Outdoor Tdew
100
90
80
70
60
50
40
30
20
10
0
50
45
40
35
30
25
20
15
10
5
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Rain
Rain
Rain (mm)
0
2
4
6
8
10
12
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Solar - Horizontal
1000
900
800
700
600
500
400
300
200
100
0
Solar (W/m²)
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
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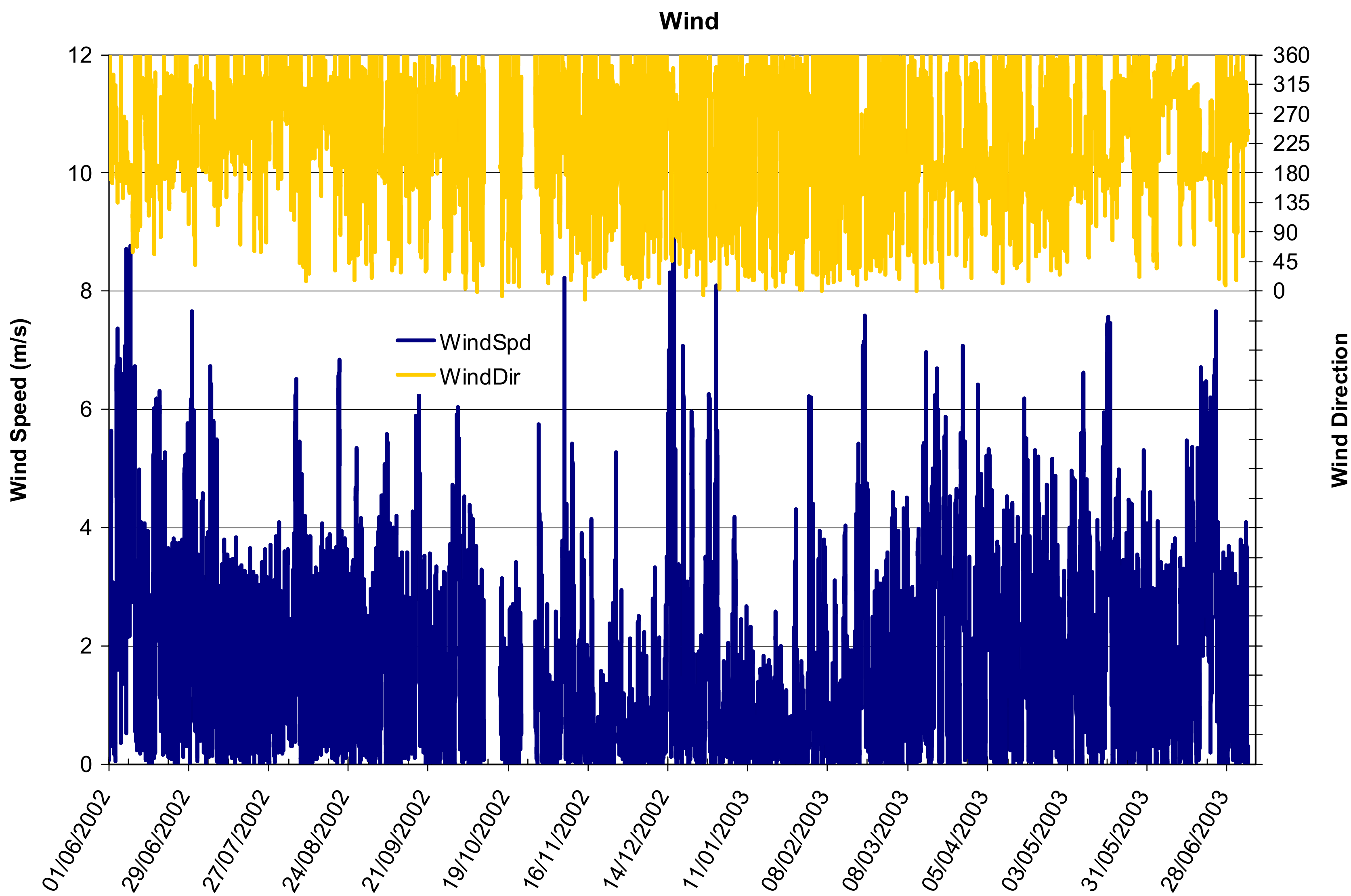
03/05/2003
31/05/2003
28/06/2003


Wind
Wind Speed (m/s)
Wind Direction
WindSpd
WindDir
0
2
4
6
8
10
12
0
45
90
135
180
225
270
315
360
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
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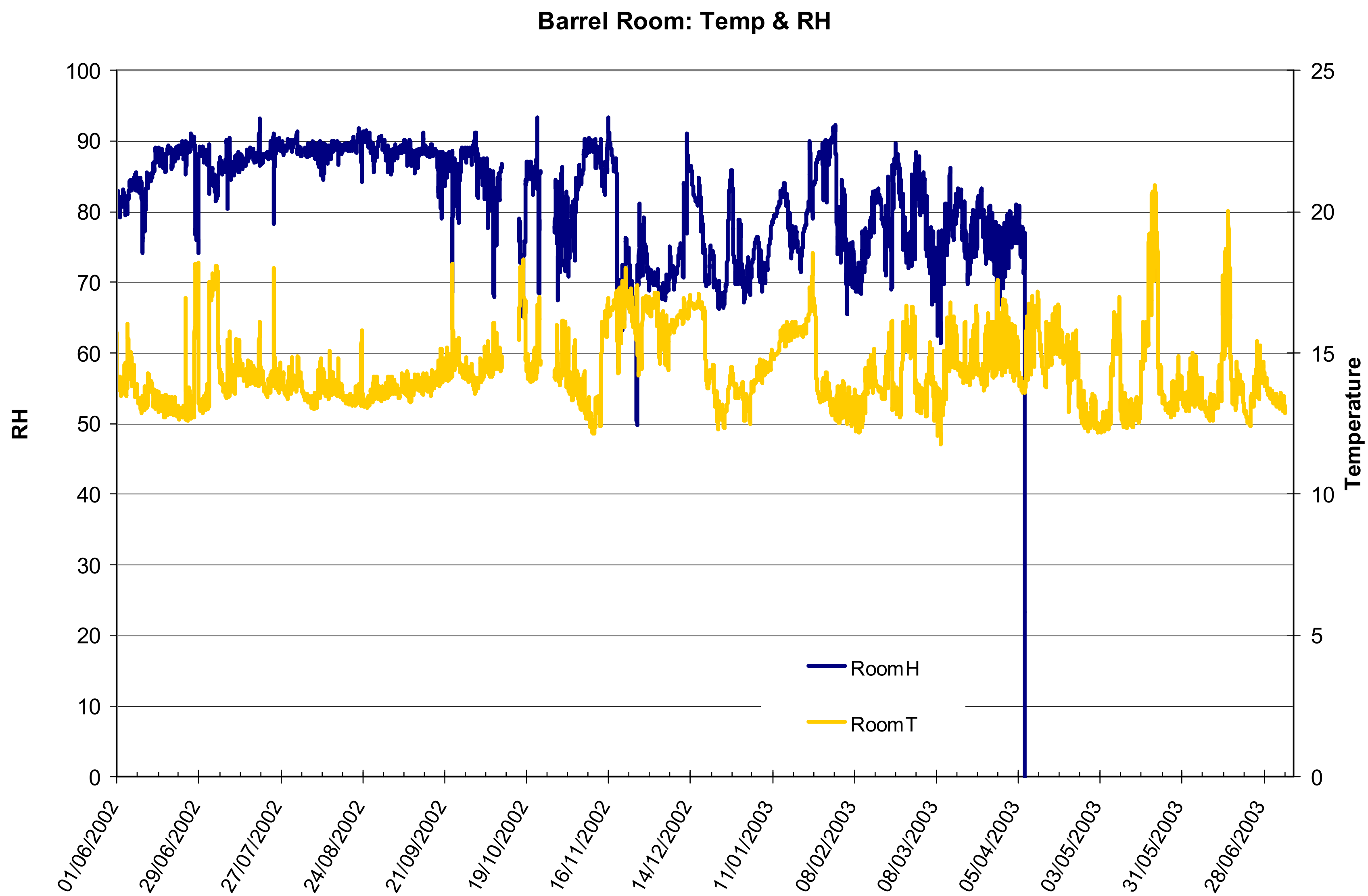
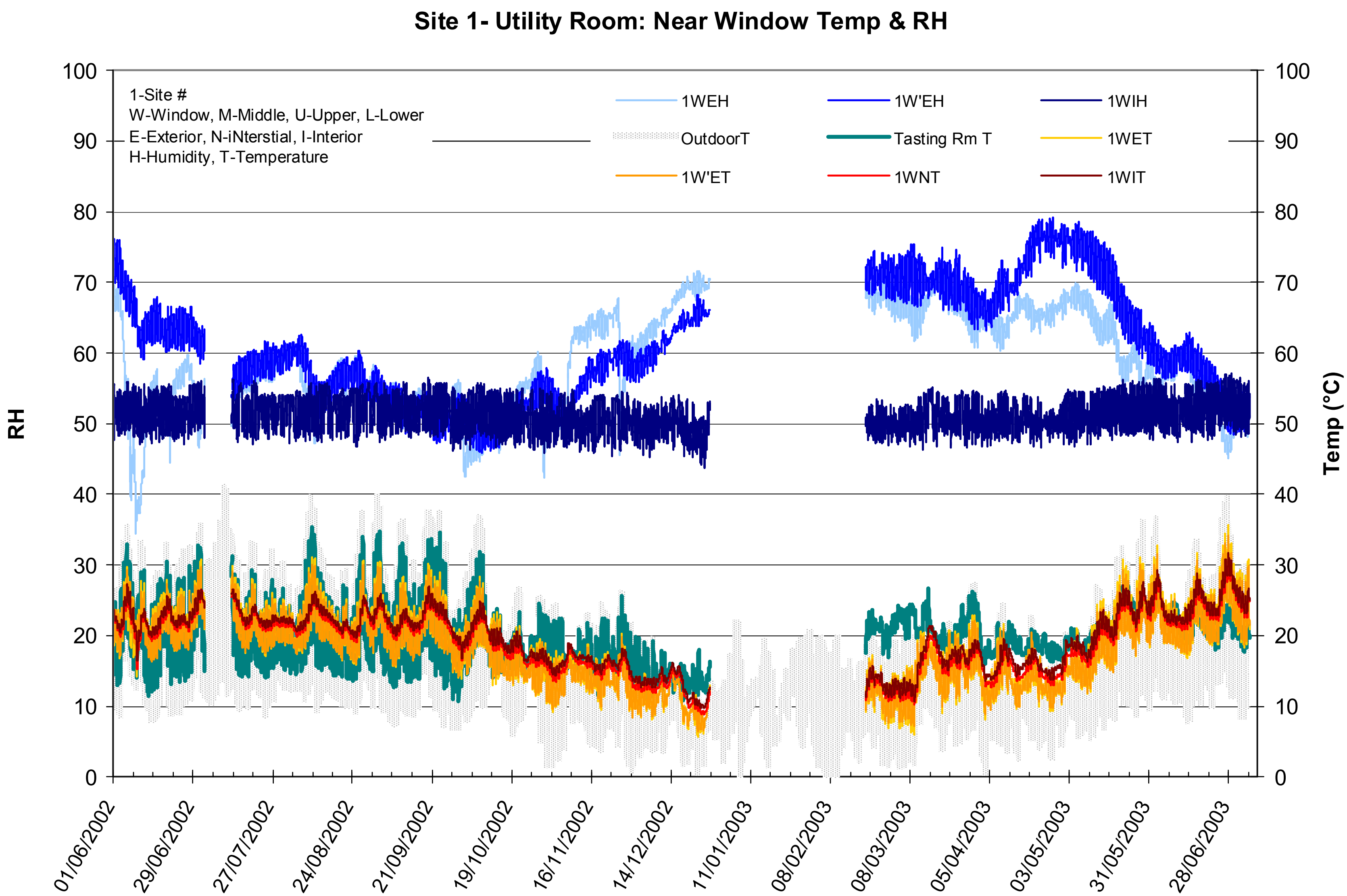
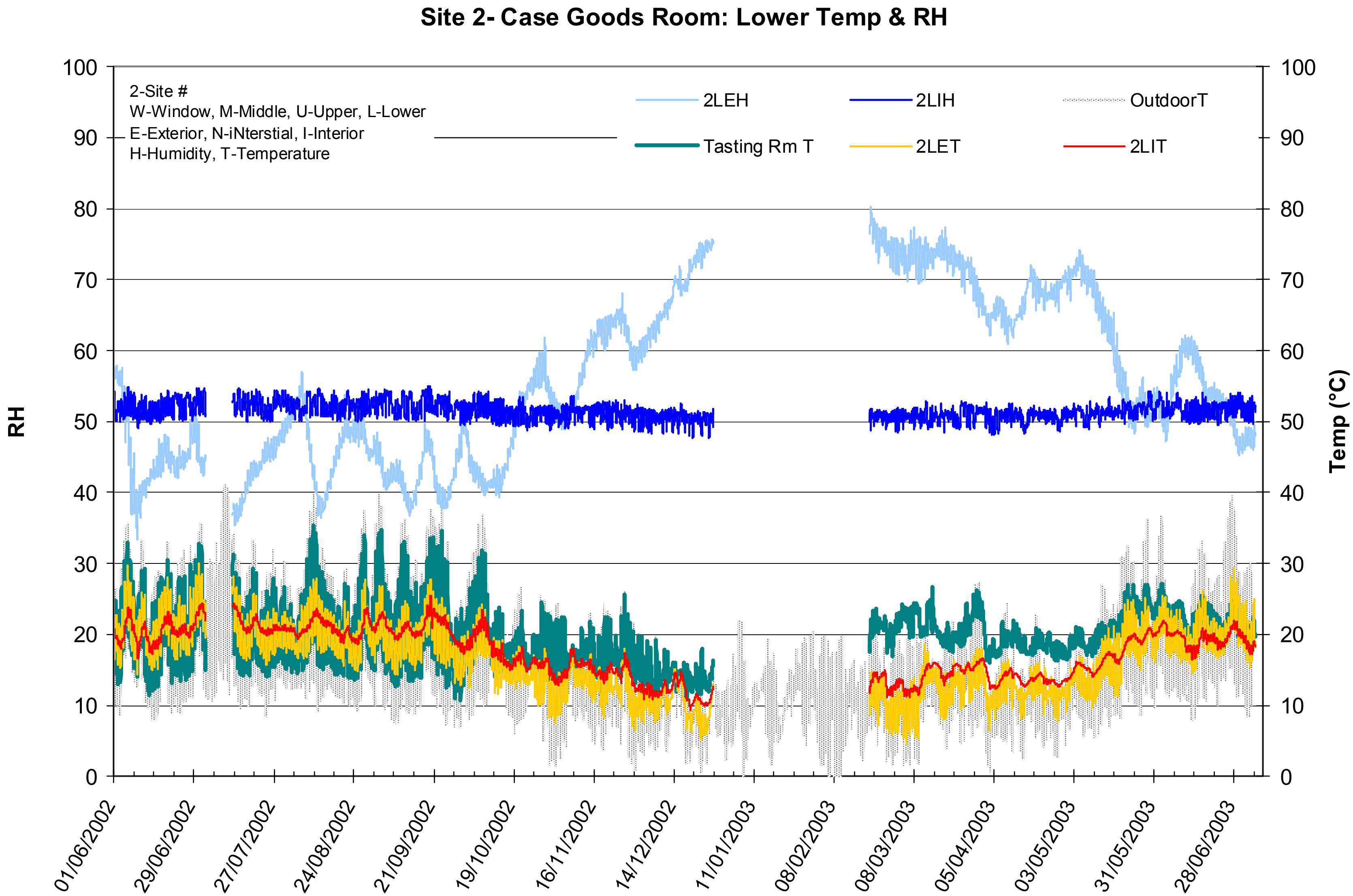
03/05/2003
31/05/2003
28/06/2003


Barrel Room: Temp & RH
RH
Temperature
100
90
80
70
60
50
40
30
20
10
0
25
20
15
10
5
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003
RoomH
RoomT


Site 1- Utility Room: Near Window Temp & RH
1-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
1WEH
1W'EH
1WIH
OutdoorT
Tasting Rm T
1WET
1W'ET
1WNT
1WIT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Site 2- Case Goods Room: Lower Temp & RH
RH
Temp (°C)
2-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
2LEH
2LIH
OutdoorT
Tasting Rm T
2LET
2LIT
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
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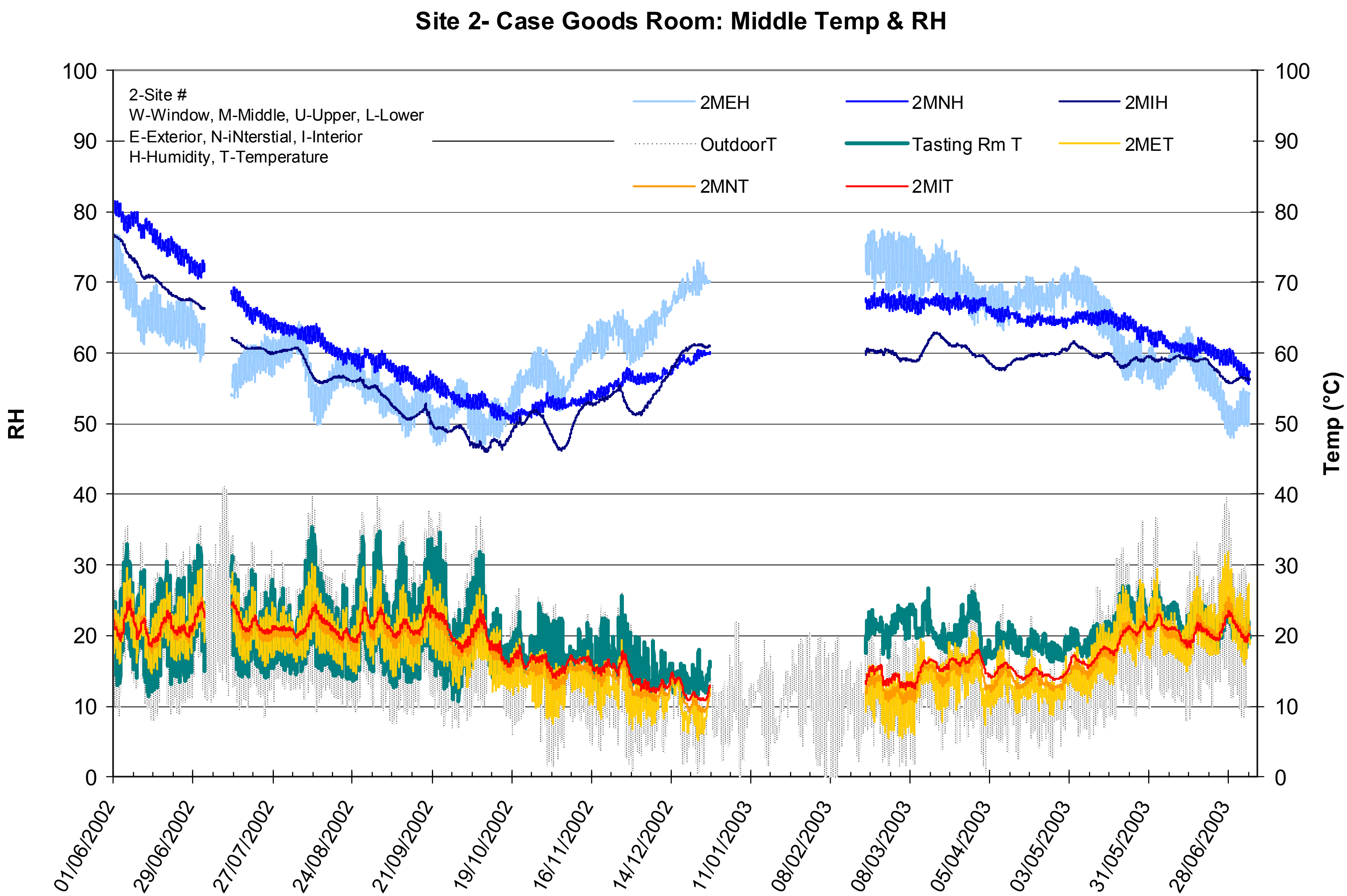
31/05/2003
28/06/2003


Site 2- Case Goods Room: Middle Temp & RH
2-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
2MEH
2MNH
2MIH
OutdoorT
Tasting Rm T
2MET
2MNT
2MIT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
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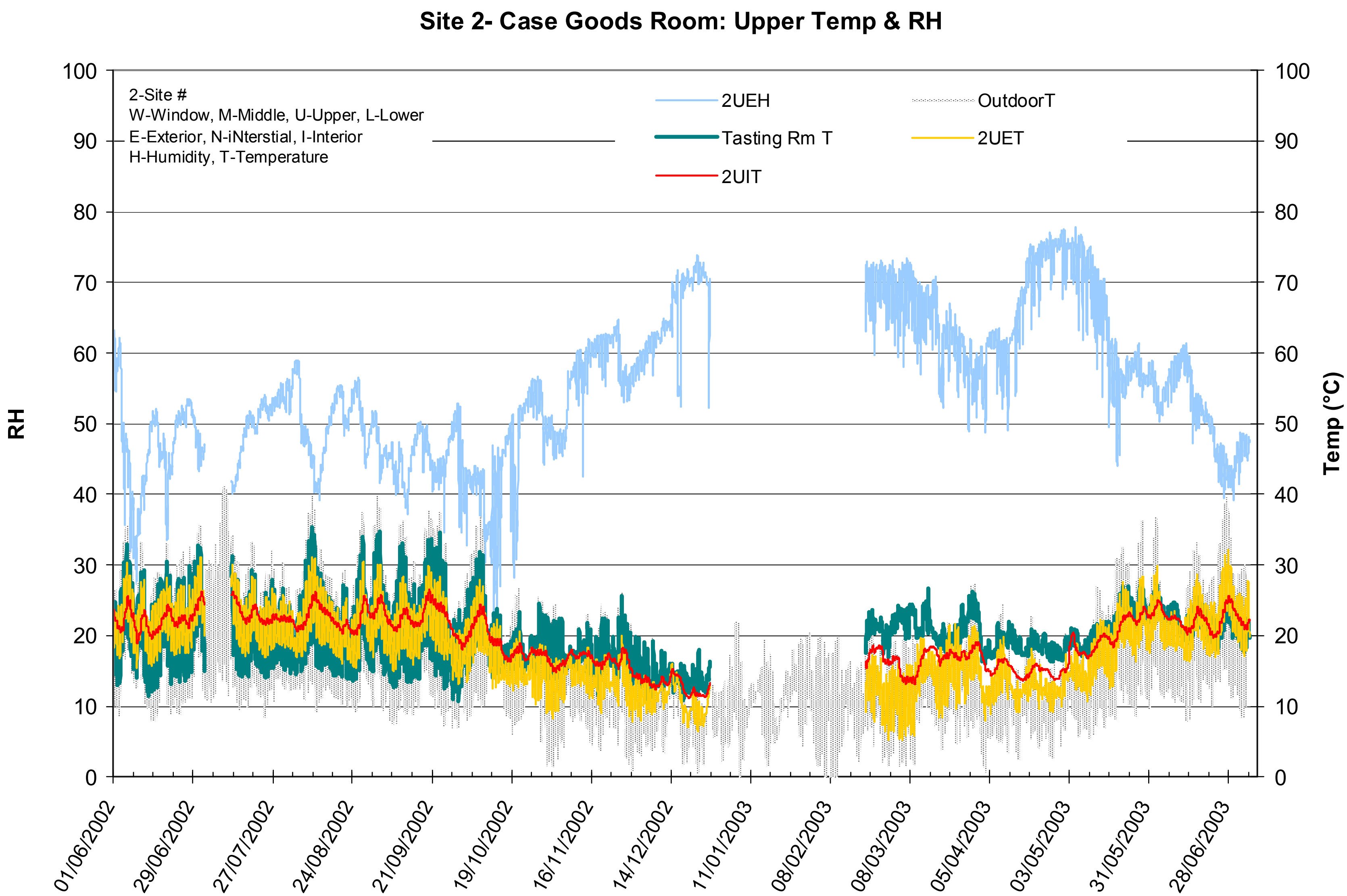
03/05/2003
31/05/2003
28/06/2003


Site 2- Case Goods Room: Upper Temp & RH
2-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
2UEH
OutdoorT
Tasting Rm T
2UET
2UIT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
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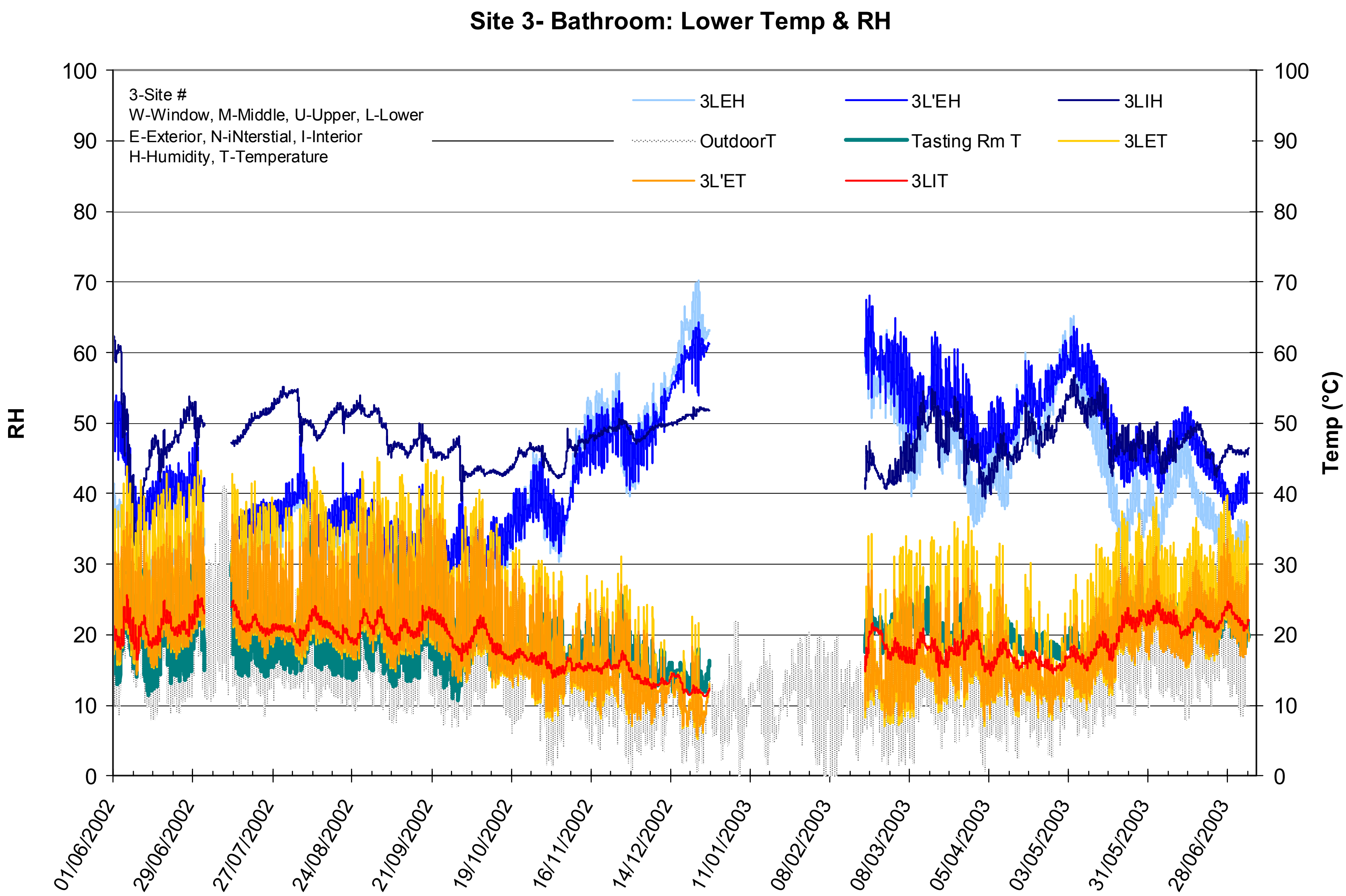
31/05/2003
28/06/2003


Site 3- Bathroom: Lower Temp & RH
3-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
3LEH
3L'EH
3LIH
OutdoorT
Tasting Rm T
3LET
3L'ET
3LIT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
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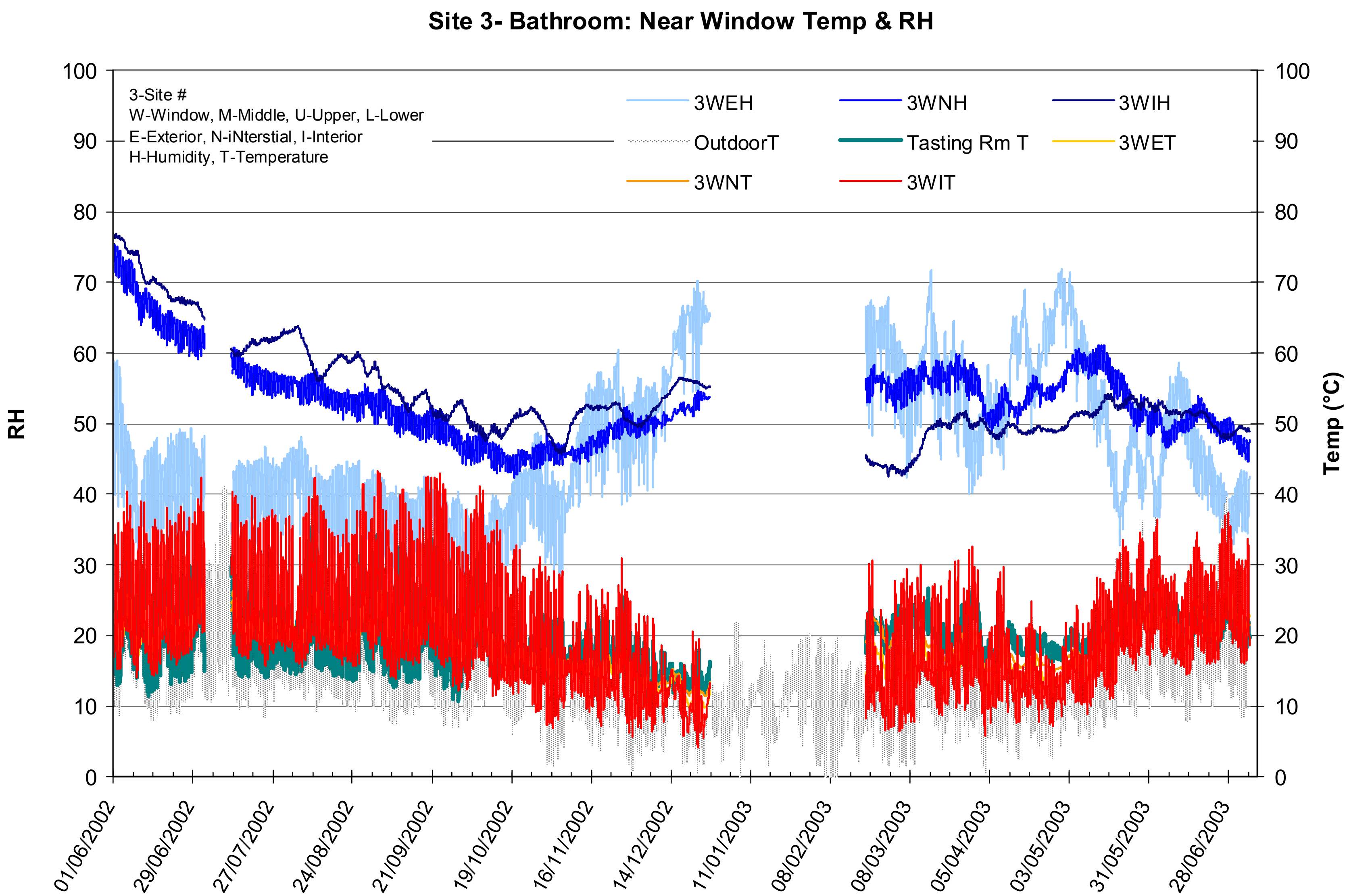
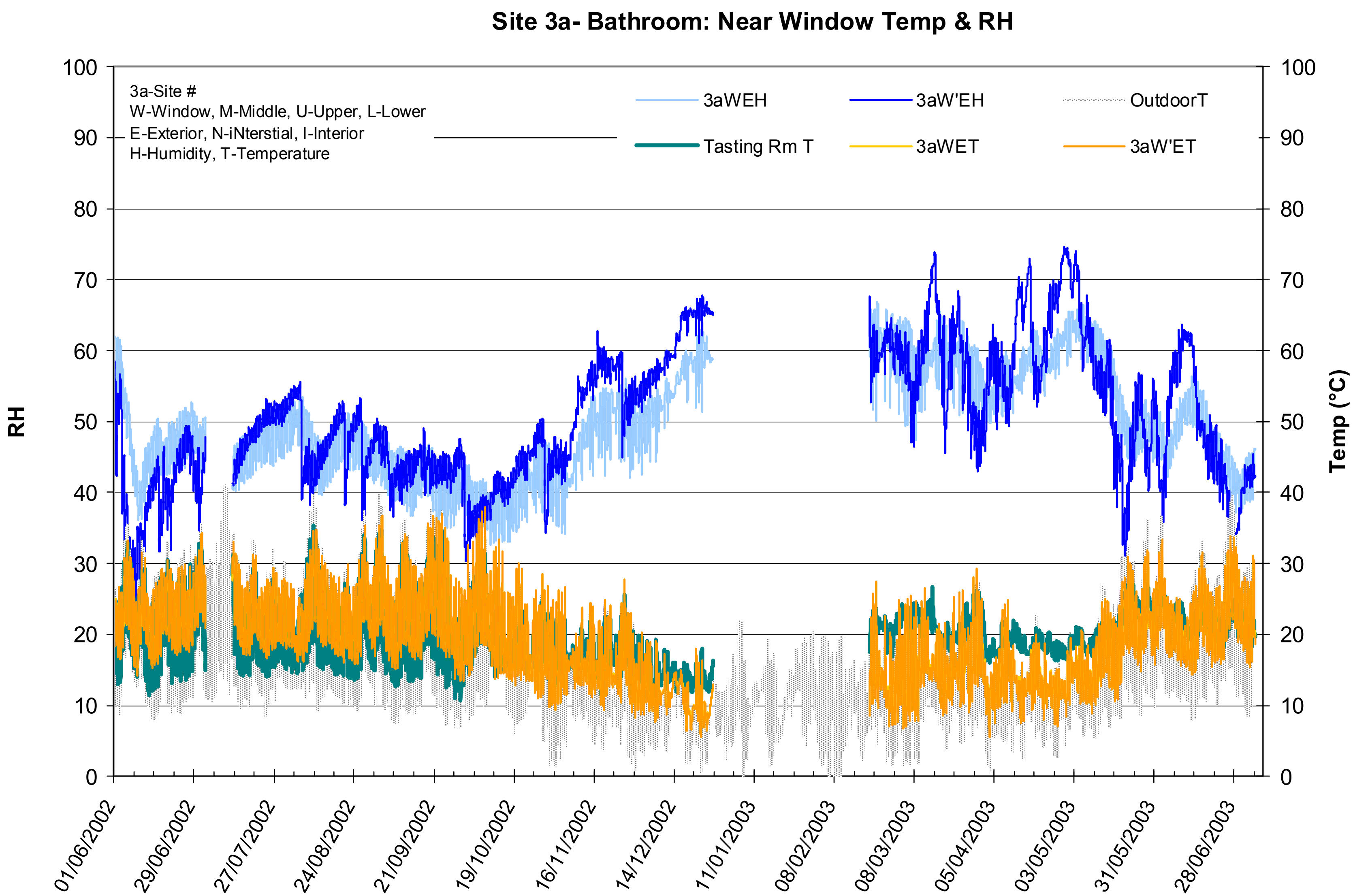
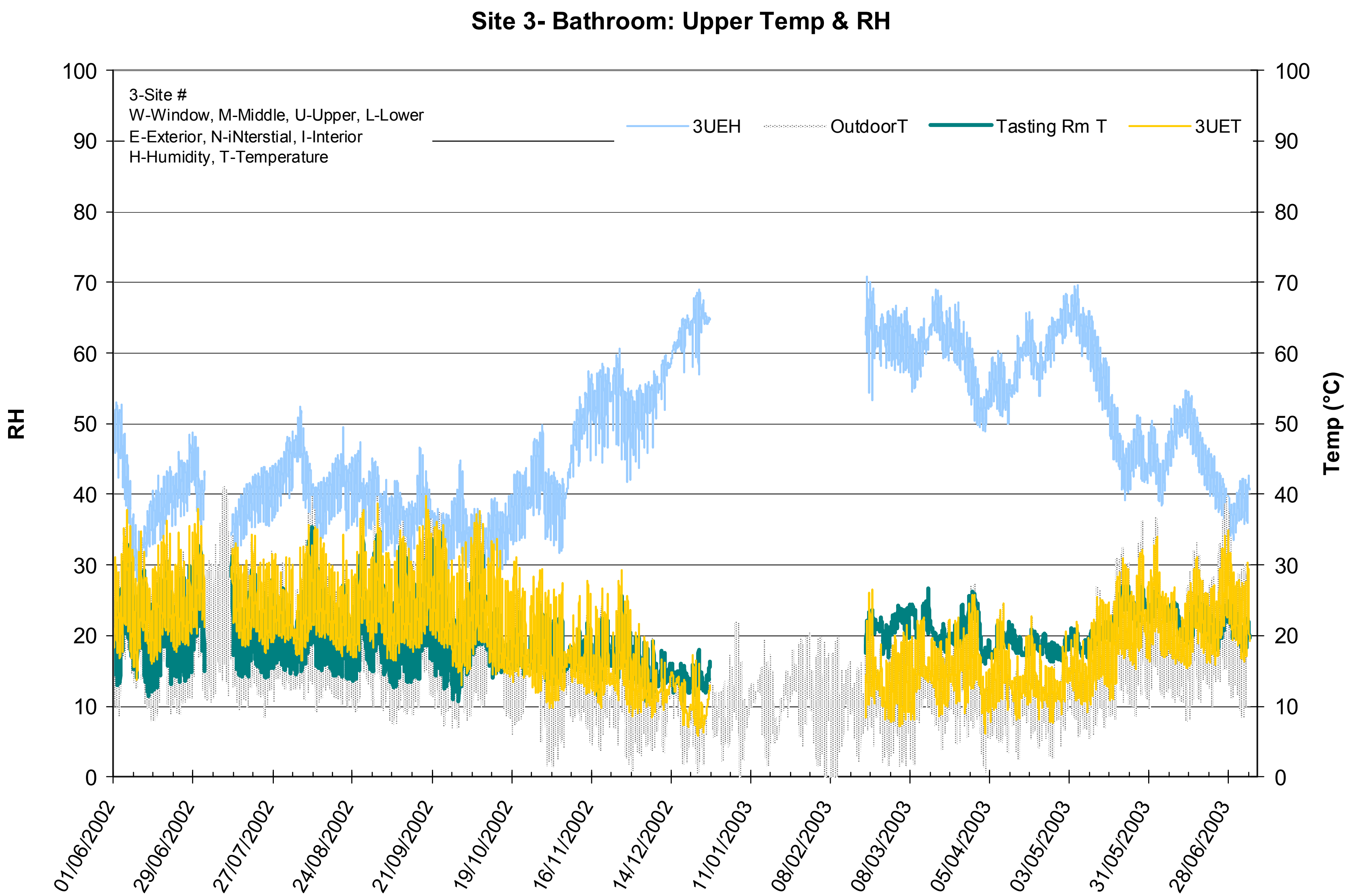
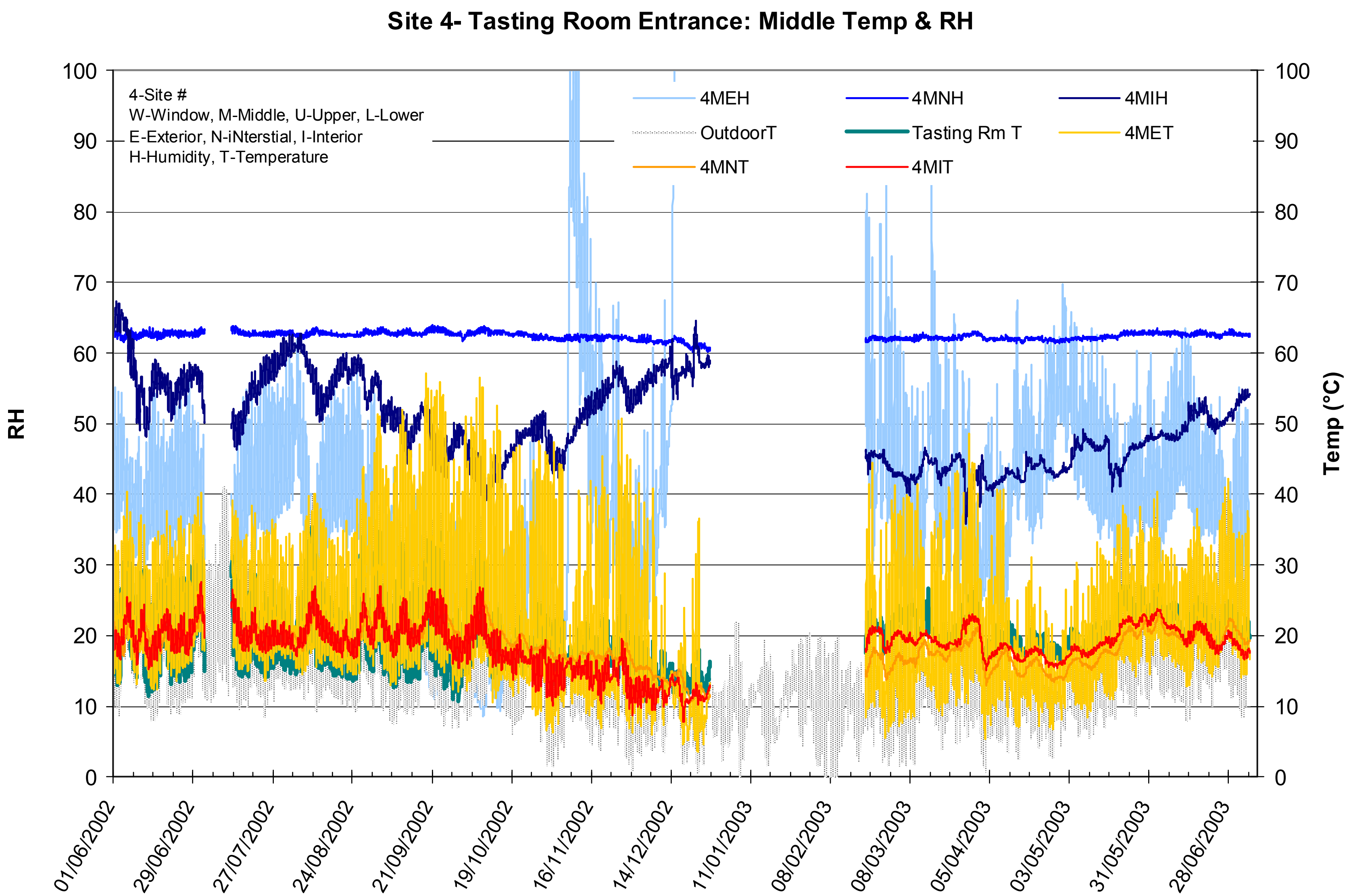
03/05/2003
31/05/2003
28/06/2003

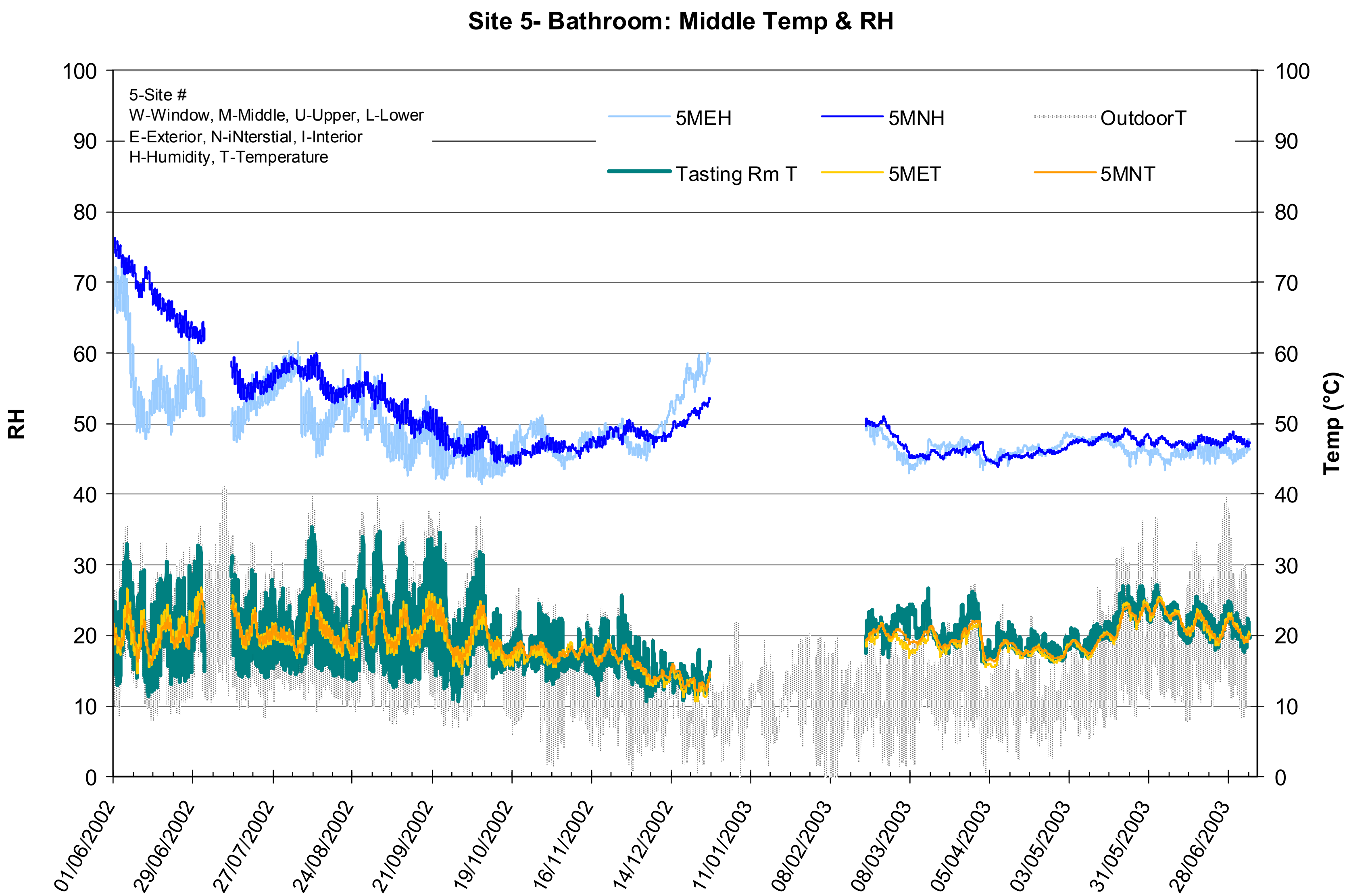

Site 3- Bathroom: Near Window Temp & RH
3-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
3WEH
3WNH
3WIH
OutdoorT
Tasting Rm T
3WET
3WNT
3WIT
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

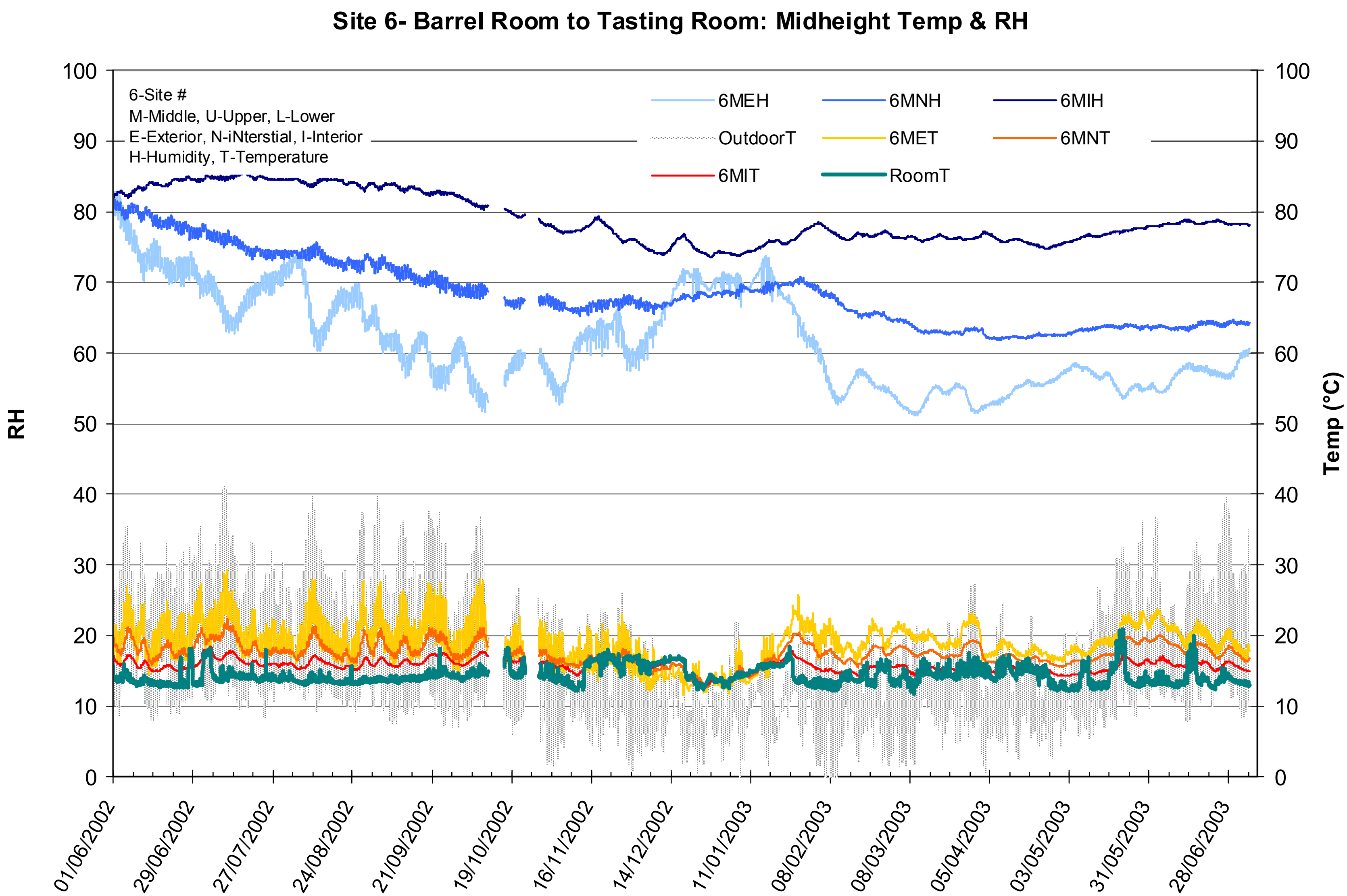


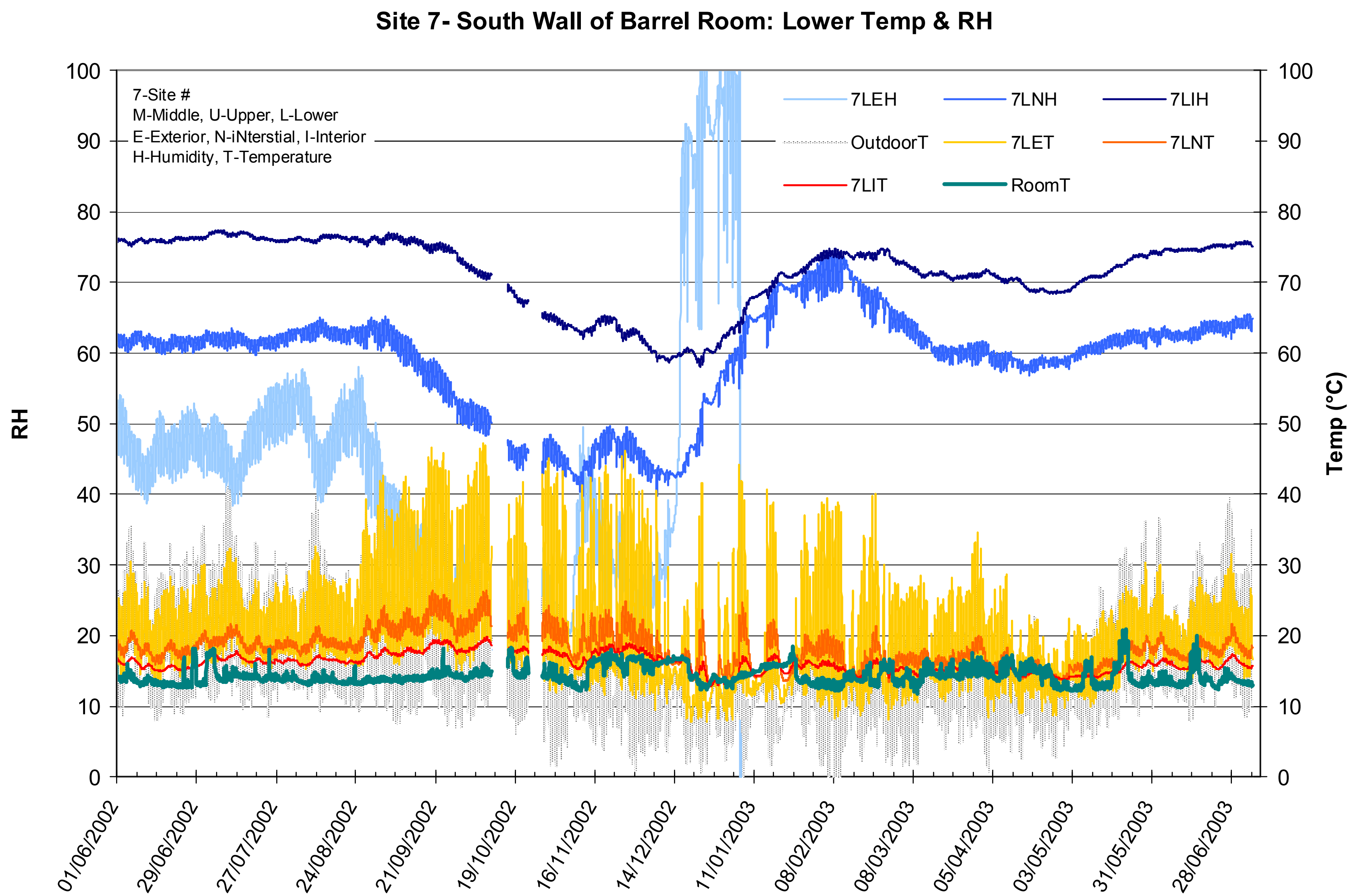
Site 3a- Bathroom: Near Window Temp & RH
3a-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
3aWEH
3aW'EH
OutdoorT
Tasting Rm T
3aWET
3aW'ET
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

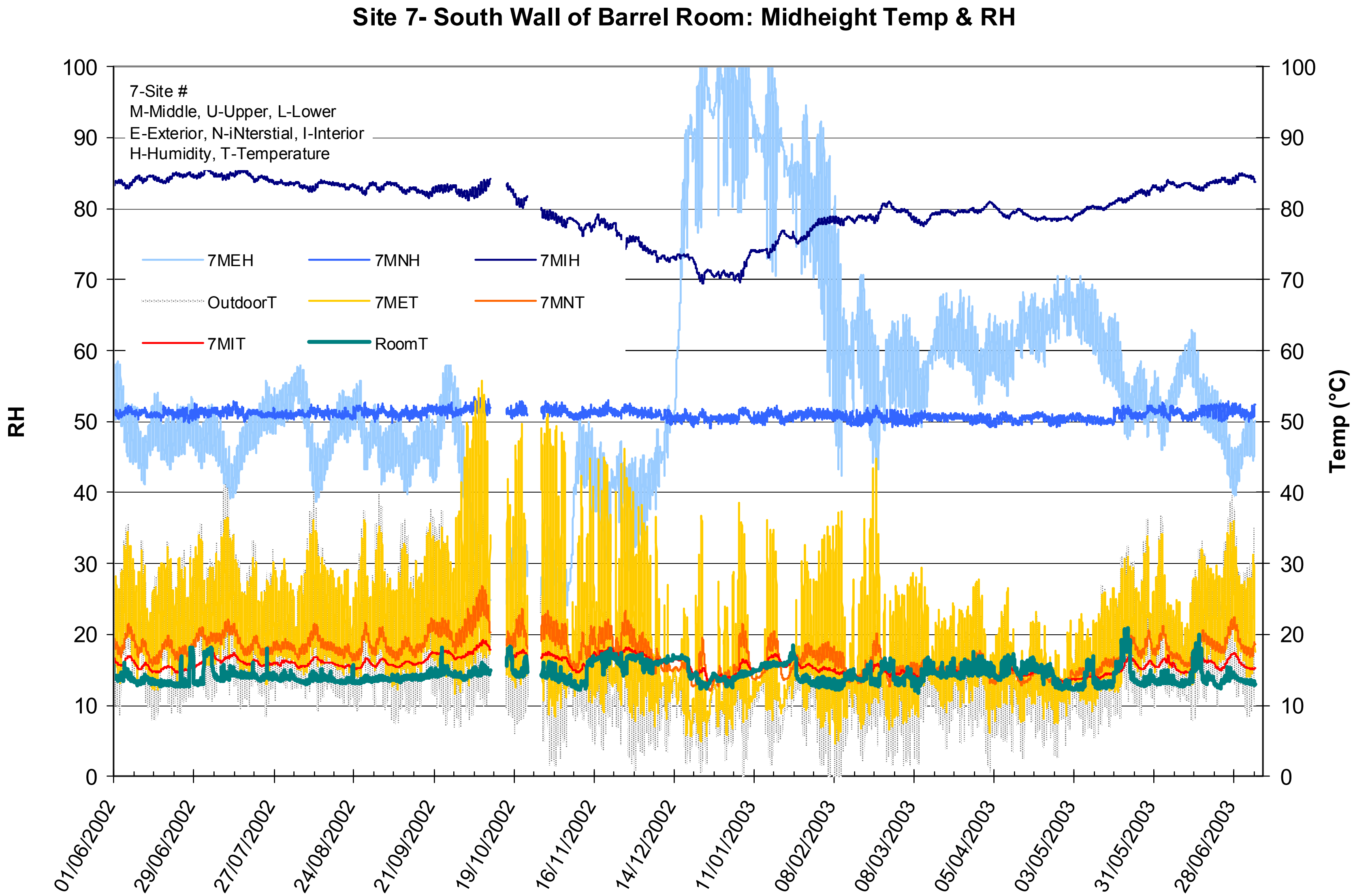

Site 3- Bathroom: Upper Temp & RH
3-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
3UEH
OutdoorT
Tasting Rm T
3UET
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

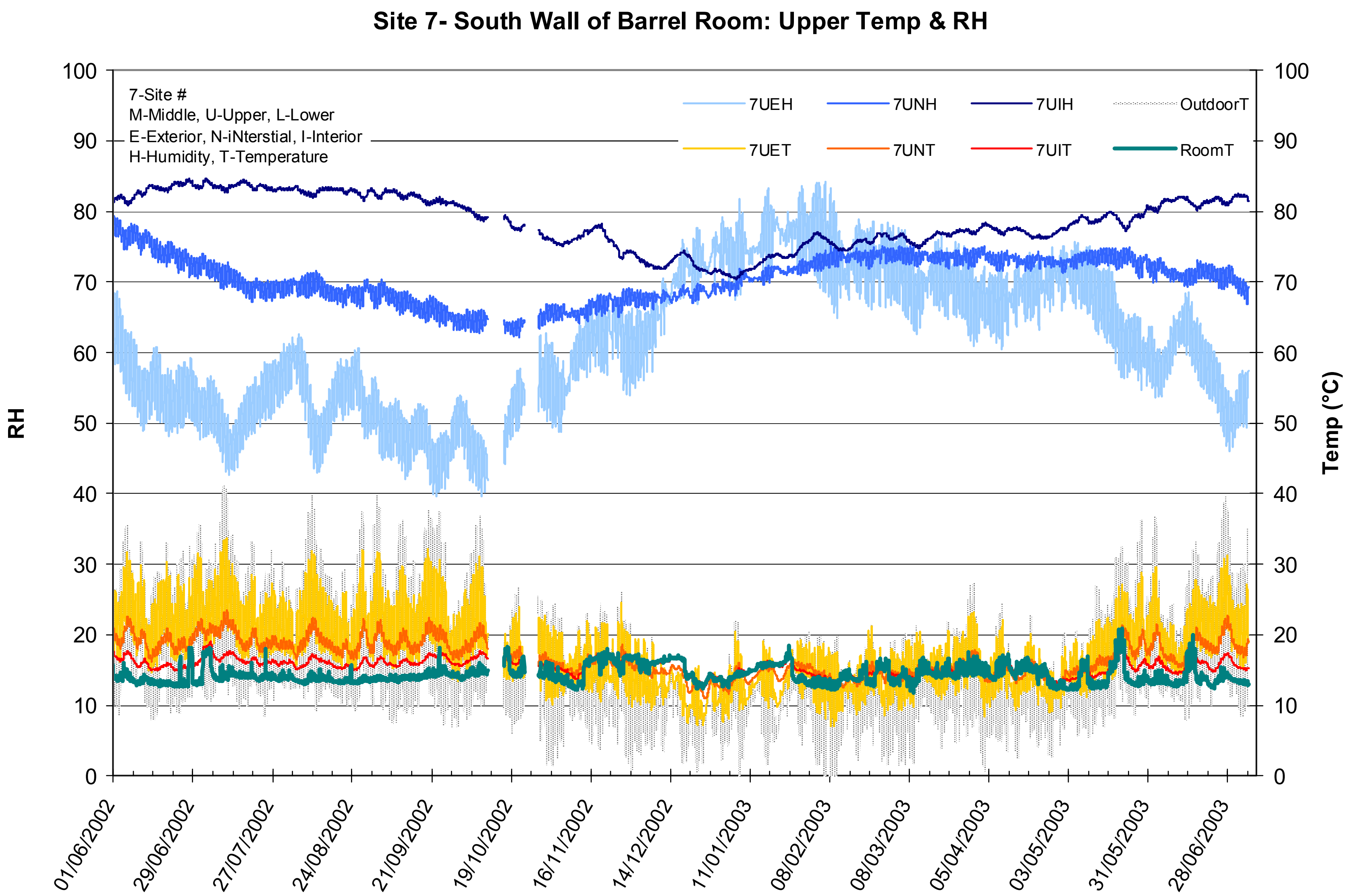

Site 4- Tasting Room Entrance: Middle Temp & RH
4-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
4MEH
4MNH
4MIH
OutdoorT
Tasting Rm T
4MET
4MNT
4MIT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

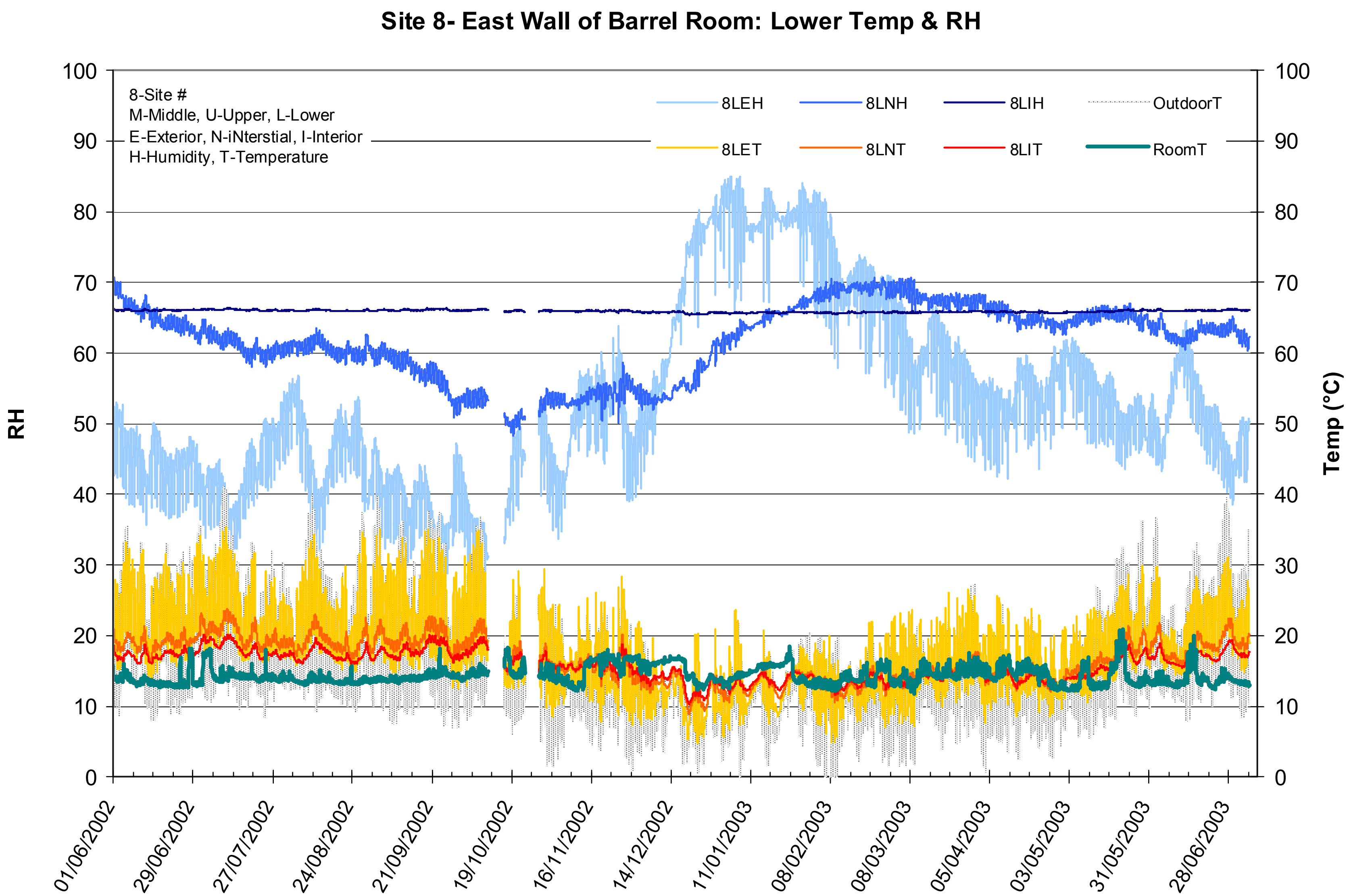

Site 5- Bathroom: Middle Temp & RH
5-Site #
W-Window, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
5MEH
5MNH
OutdoorT
Tasting Rm T
5MET
5MNT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Site 6- Barrel Room to Tasting Room: Midheight Temp & RH
6-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
6MEH
6MNH
6MIH
OutdoorT
6MET
6MNT
6MIT
RoomT
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

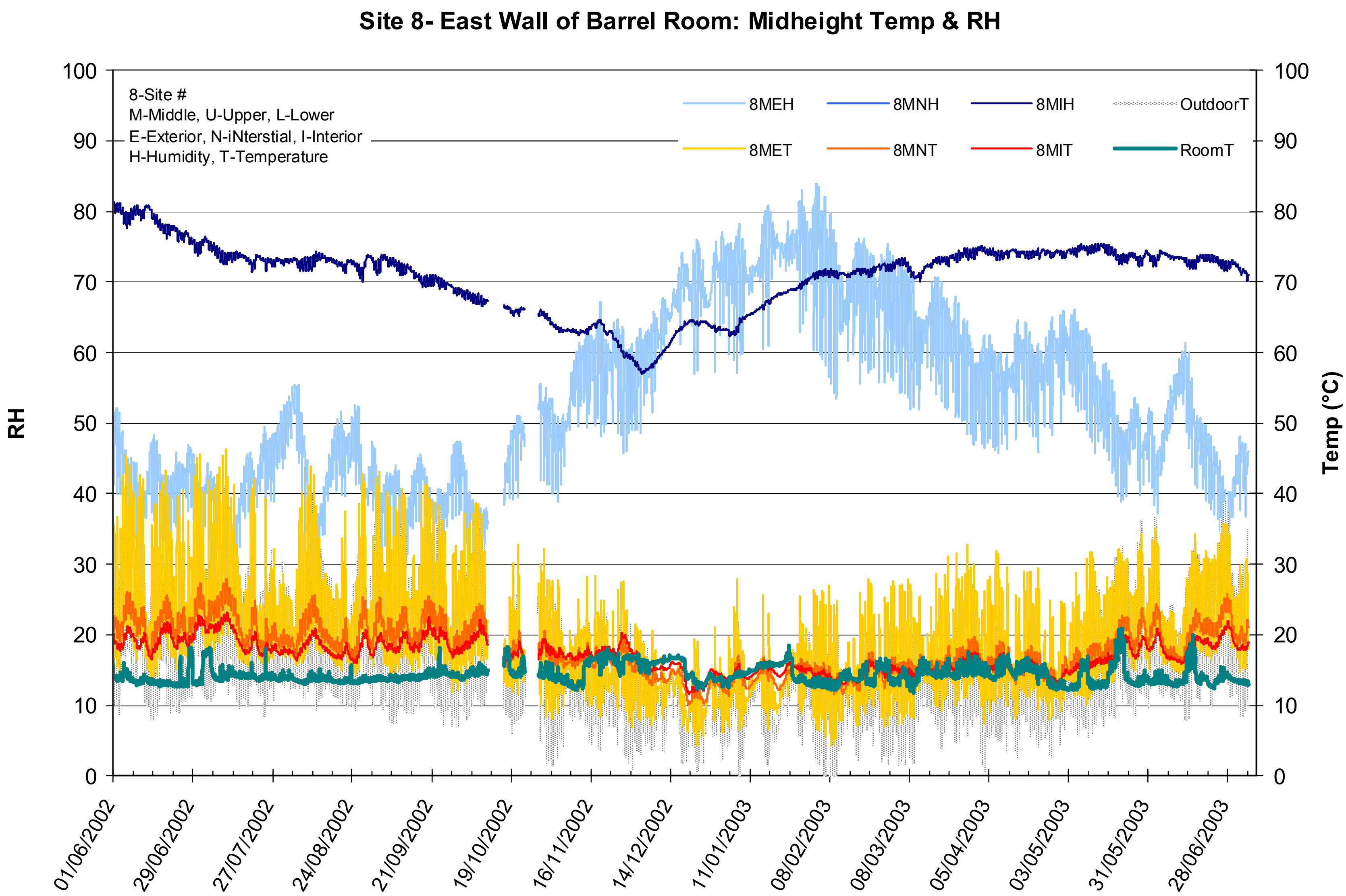

Site 7- South Wall of Barrel Room: Lower Temp & RH
7-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
7LEH
7LNH
7LIH
OutdoorT
7LET
7LNT
7LIT
RoomT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

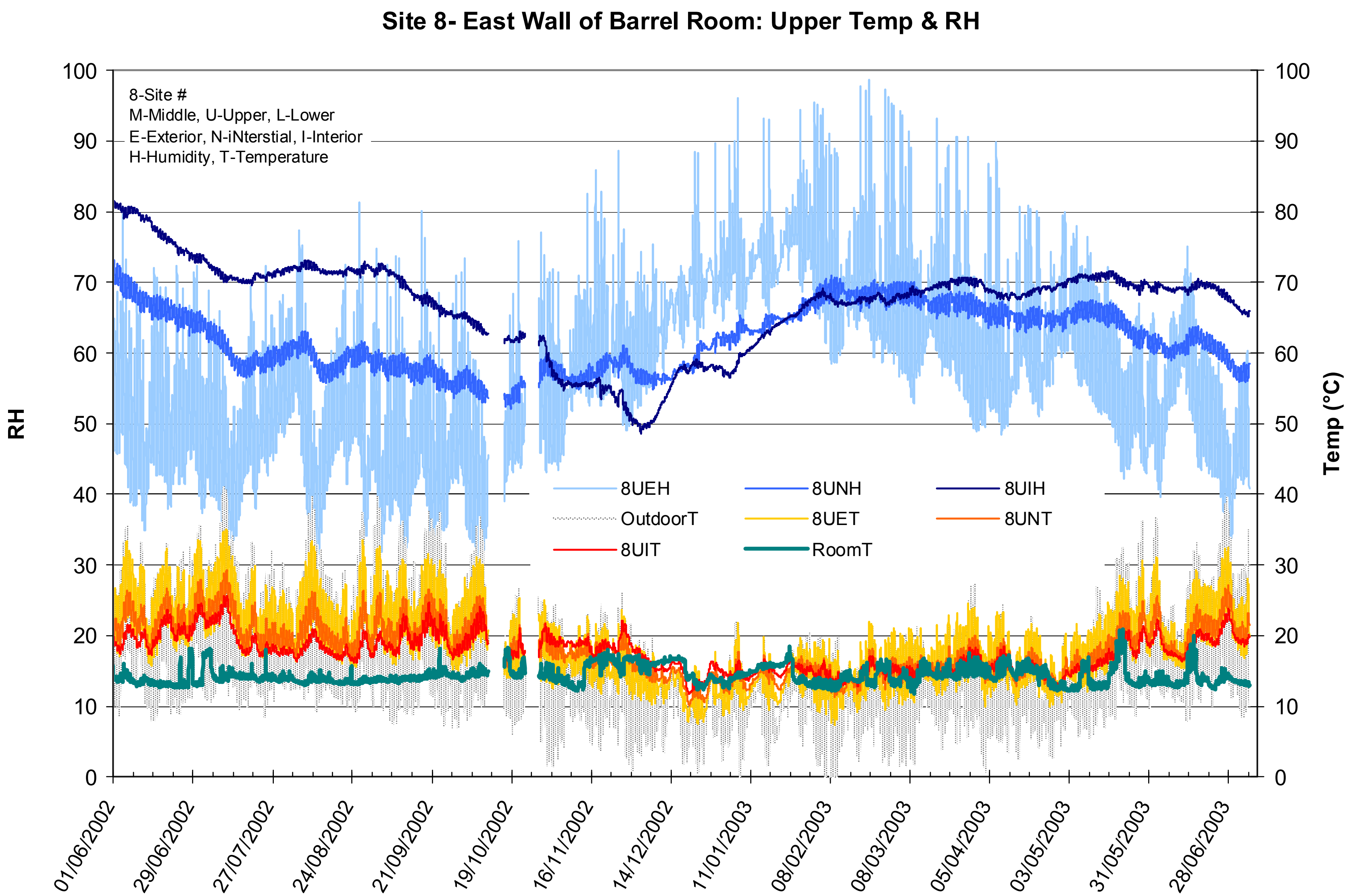

Site 7- South Wall of Barrel Room: Midheight Temp & RH
7-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
7MEH
7MNH
7MIH
OutdoorT
7MET
7MNT
7MIT
RoomT
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Site 7- South Wall of Barrel Room: Upper Temp & RH
7-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
7UEH
7UNH
7UIH
OutdoorT
7UET
7UNT
7UIT
RoomT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

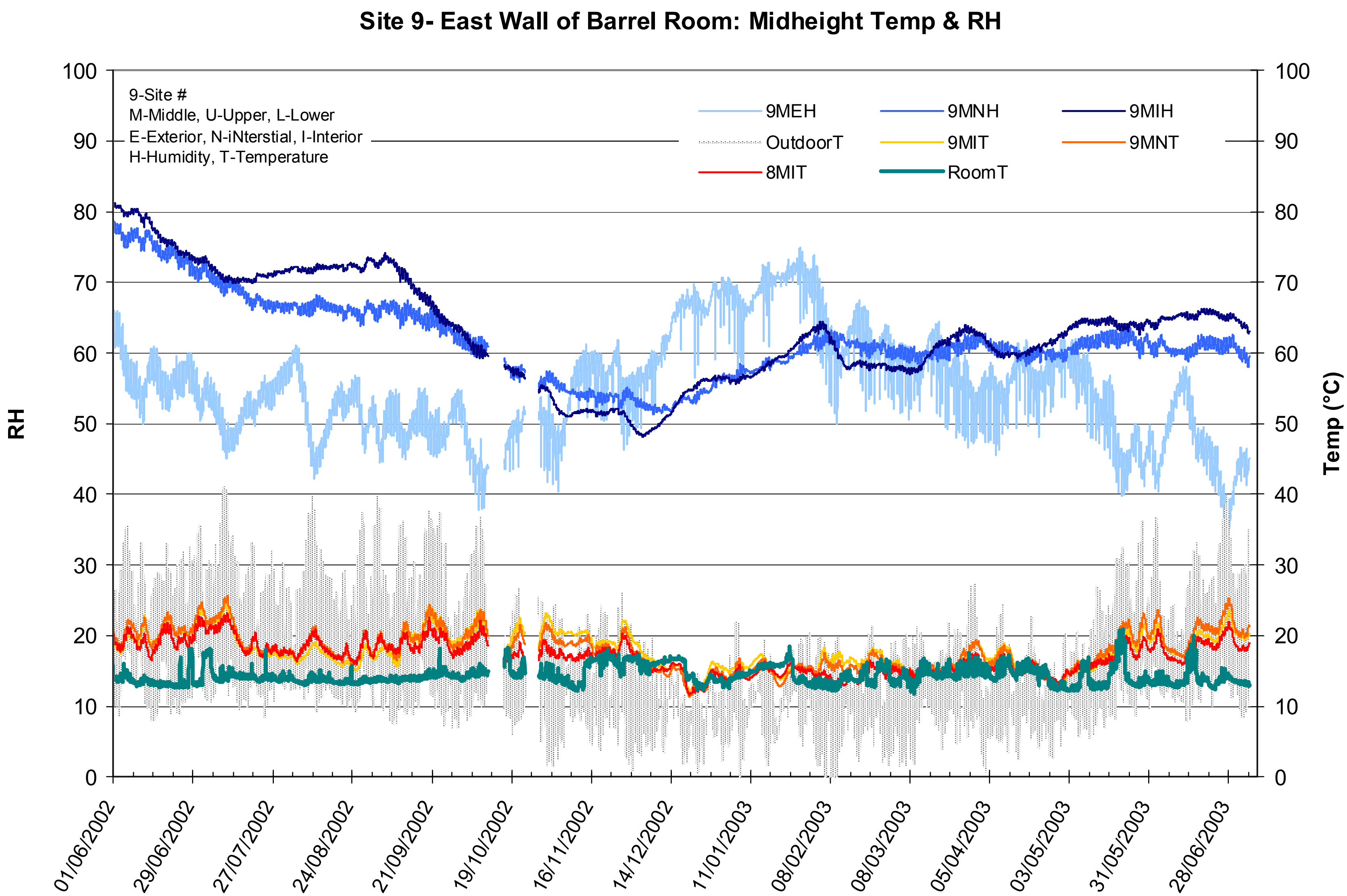


Site 8- East Wall of Barrel Room: Lower Temp & RH
8-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
8LEH
8LNH
8LIH
OutdoorT
8LET
8LNT
8LIT
RoomT
RH
Temp (°C)
100
90
80
70
60
50
40
30
20
10
0
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

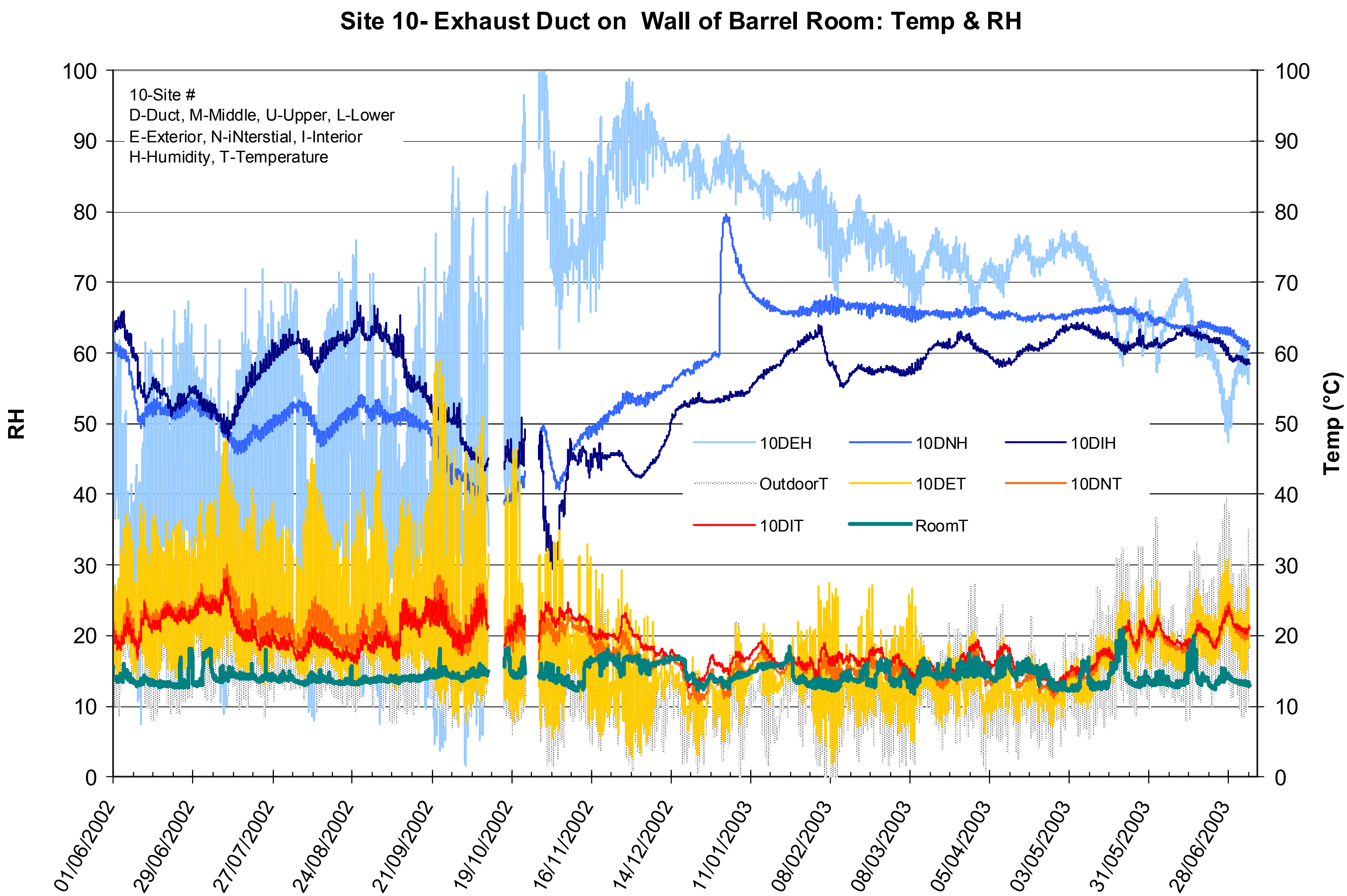

Site 8- East Wall of Barrel Room: Midheight Temp & RH
8-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
8MEH
8MNH
8MIH
OutdoorT
8MET
8MNT
8MIT
RoomT
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

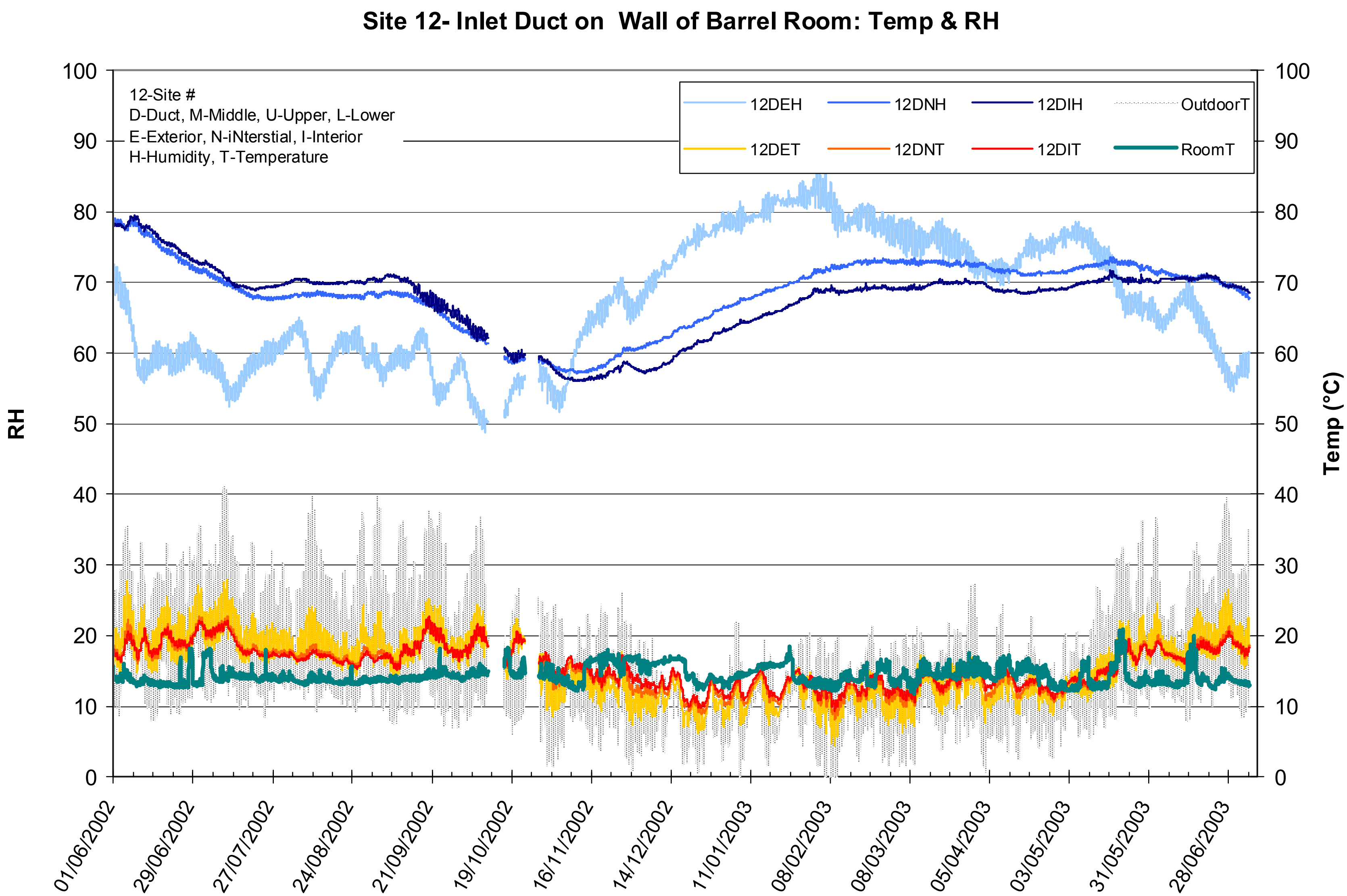


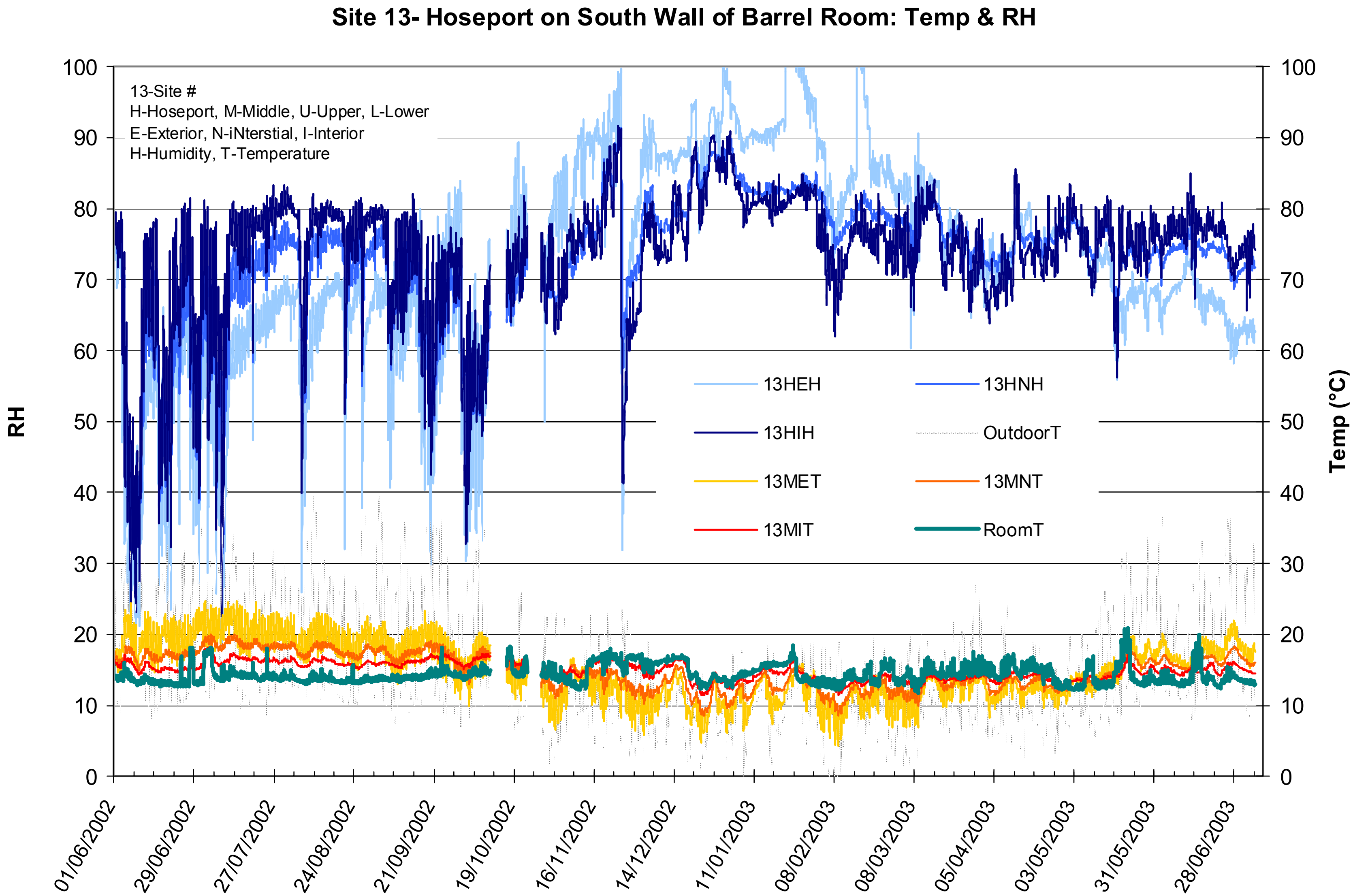
Site 8- East Wall of Barrel Room: Upper Temp & RH
8-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
RH
Temp (°C)
8UEH
8UNH
8UIH
OutdoorT
8UET
8UNT
8UIT
RoomT
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003



Site 9- East Wall of Barrel Room: Midheight Temp & RH
9-Site #
M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
9MEH
9MNH
9MIH
OutdoorT
9MIT
9MNT
8MIT
RoomT
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Site 10- Exhaust Duct on Wall of Barrel Room: Temp & RH
10-Site #
D-Duct, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
10DEH
10DNH
10DIH
OutdoorT
10DET
10DNT
10DIT
RoomT
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Site 12- Inlet Duct on Wall of Barrel Room: Temp & RH
12-Site #
D-Duct, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
12DEH
12DNH
12DIH
OutdoorT
12DET
12DNT
12DIT
RoomT
RH
Temp (°C)
0
10
20
30
40
50
60
70
80
90
100
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003


Site 13- Hoseport on South Wall of Barrel Room: Temp & RH
13-Site #
H-Hoseport, M-Middle, U-Upper, L-Lower
E-Exterior, N-iNterstial, I-Interior
H-Humidity, T-Temperature
RH
Temp (°C)
13HEH
13HNH
13HIH
OutdoorT
13MET
13MNT
13MIT
RoomT
01/06/2002
29/06/2002
27/07/2002
24/08/2002
21/09/2002
19/10/2002
16/11/2002
14/12/2002
11/01/2003
08/02/2003
08/03/2003
05/04/2003
03/05/2003
31/05/2003
28/06/2003

Site 2 – Interior View

Site 4 – Interior View

Site 9 – Interior View and Exterior View

Site 8 – Interior View and Exterior View