APPENDIX A

CLIMATE

Five tables are presented in this appendix that are related to those found in chapter 2 section 2.3.1

Table A1: The observed and Hadley output overall monthly average temperature and relative humidity at Paris, used to calculate the calibration.

	Temperature			Relative Humidity		
Month	**Observed**	**Hadley**	**Difference**	**Observed**	**Hadley**	**Ratio**
Jan	4.4	1.83	2.57	85.5	94.1	0.91
Feb	4.88	3.10	1.78	83.1	90.7	0.92
Mar	8.27	5.59	2.68	74.7	87.8	0.85
Apr	10.2	7.80	2.40	71.4	84.9	0.84
May	14.46	12.40	2.06	70.3	82.9	0.85
Jun	16.91	15.71	1.20	70.9	84.9	0.84
Jul	19.42	17.53	1.89	69.3	83.1	0.83
Aug	19.84	17.23	2.61	66.9	78.9	0.85
Sep	15.8	13.65	2.15	75.4	81.2	0.93
Oct	10.93	8.71	2.22	81.7	91.8	0.89
Nov	7.18	4.89	2.29	86.6	93.2	0.93
Dec	4.58	2.15	2.43	86.9	94.8	0.92

Table A2: The observed and Hadley output overall monthly average temperature and relative humidity at Prauge, used to calculate the calibration.

	Temperature			Relative Humidity		
Month	**Observed**	**Hadley**	**Difference**	**Observed**	**Hadley**	**Ratio**
Jan	-1.49	-3.08	1.59	86.4	95.5	0.90
Feb	-0.62	-2.73	2.10	82.8	94.6	0.88
Mar	3.58	1.90	1.68	76.2	89.0	0.86
Apr	7.89	6.34	1.55	67.1	85.2	0.79
May	13.23	10.94	2.28	68.0	84.0	0.81
Jun	15.73	15.63	0.10	69.7	84.8	0.82
Jul	17.77	17.40	0.37	68.9	85.2	0.81
Aug	17.77	15.58	2.18	69.0	84.5	0.82
Sep	13.27	11.33	1.94	76.0	85.8	0.89
Oct	8.39	6.65	1.74	80.6	90.7	0.89
Nov	2.70	1.70	1.00	86.6	94.0	0.92
Dec	-0.36	-2.40	2.03	87.1	94.5	0.92

Table A3: The observed and Hadley output overall monthly average temperature and relative humidity at Almeria, used to calculate the calibration.

	Temperature			Relative Humidity		
Month	**Observed**	**Hadley**	**Difference**	**Observed**	**Hadley**	**Ratio**
Jan	12.5	13.07	-0.57	69	76.5	0.90
Feb	13.2	12.77	0.43	68	76.1	0.89
Mar	14.7	13.62	1.08	66	77.9	0.85
Apr	16.4	14.61	1.79	64	81.0	0.79
May	19.1	15.95	3.15	66	83.5	0.79
Jun	22.7	17.16	5.54	64	90.0	0.71
Jul	25.7	18.13	7.57	63	94.0	0.67
Aug	26.4	18.63	7.77	65	92.9	0.70
Sep	24	18.65	5.35	66	87.5	0.75
Oct	20	17.95	2.05	68	81.6	0.83
Nov	16.2	16.02	0.18	70	76.0	0.92
Dec	13.7	14.06	-0.36	70	76.1	0.92

Table A4: The observed and Hadley output overall monthly average temperature and relative humidity at Oviedo, used to calculate the calibration.

	Temperature			Relative Humidity		
Month	**Observed**	**Hadley**	**Difference**	**Observed**	**Hadley**	**Ratio**
Jan	8	2.62	5.38	76	90.5	0.84
Feb	8.8	3.22	5.58	75	89.3	0.84
Mar	10	5.50	4.50	75	86.6	0.87
Apr	10.6	7.72	2.88	77	86.0	0.90
May	13.3	10.12	3.18	79	87.0	0.91
Jun	16.1	12.32	3.78	80	90.5	0.88
Jul	18.3	14.46	3.84	80	91.9	0.87
Aug	18.7	13.60	5.10	81	91.1	0.89
Sep	17.3	11.33	5.97	79	91.3	0.87
Oct	14	8.27	5.73	79	92.0	0.86
Nov	10.8	5.17	5.63	78	90.1	0.87
Dec	9	3.02	5.98	76	91.0	0.84

Table A5: The observed and Hadley output overall monthly average temperature and relative humidity at Leon, used to calculate the calibration.

	Temperature			Relative Humidity		
Month	**Observed**	**Hadley**	**Difference**	**Observed**	**Hadley**	**Ratio**
Jan	2.9	2.62	0.28	82	90.5	0.91
Feb	4.4	3.22	1.18	75	89.3	0.84
Mar	6.5	5.50	1.00	66	86.6	0.76
Apr	8	7.72	0.28	65	86.0	0.76
May	11.9	10.12	1.78	63	87.0	0.72
Jun	16.4	12.32	4.08	59	90.5	0.65
Jul	20	14.46	5.54	55	91.9	0.60
Aug	19.9	13.60	6.30	56	91.1	0.61
Sep	16.3	11.33	4.97	63	91.3	0.69
Oct	11.1	8.27	2.83	74	92.0	0.80
Nov	6.5	5.17	1.33	80	90.1	0.89
Dec	4	3.02	0.98	83	91.0	0.91

APPENDIX B

BUILDING SIMULATION

Filters

This follows on from the triangular filter discussed in section 3.2.4 of chapter 3.

Square filter

This filter gives an equal weighting to each of the observed values that is used to give a smoothed series (figure B2). Again various time windows were investigated, and the best prediction used a 48 period window. Therefore for each observed value 1/48th of the value was used, and summed with the previous 48 periods to give the smoothed value. Again this had little effect on the prediction. The correlation coefficient improved slightly, R^2=0.32, but the overall prediction is still inadequate.

The best prediction so far was the original method (section 3.2.2), so the shape of the filter was determined (figure B1), as were the following filters (figure B2). Note the length of the original function was only half a day compared to a full day, and therefore the scales are also different. Another point to mention is that all of the weighting values sum to 1, the filters just change where the total of the data comes from within the smoothing window.

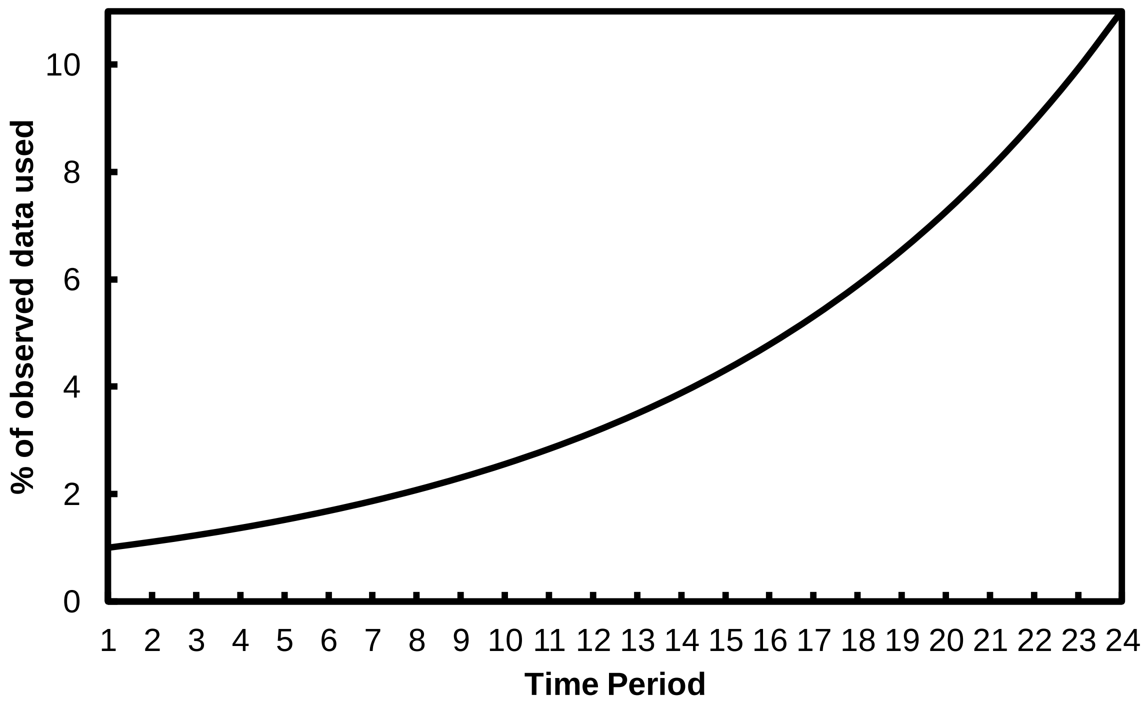


Figure B1: The shape of the original smoothing function, giving more weight to the most recent data, and little weighting to the oldest data.

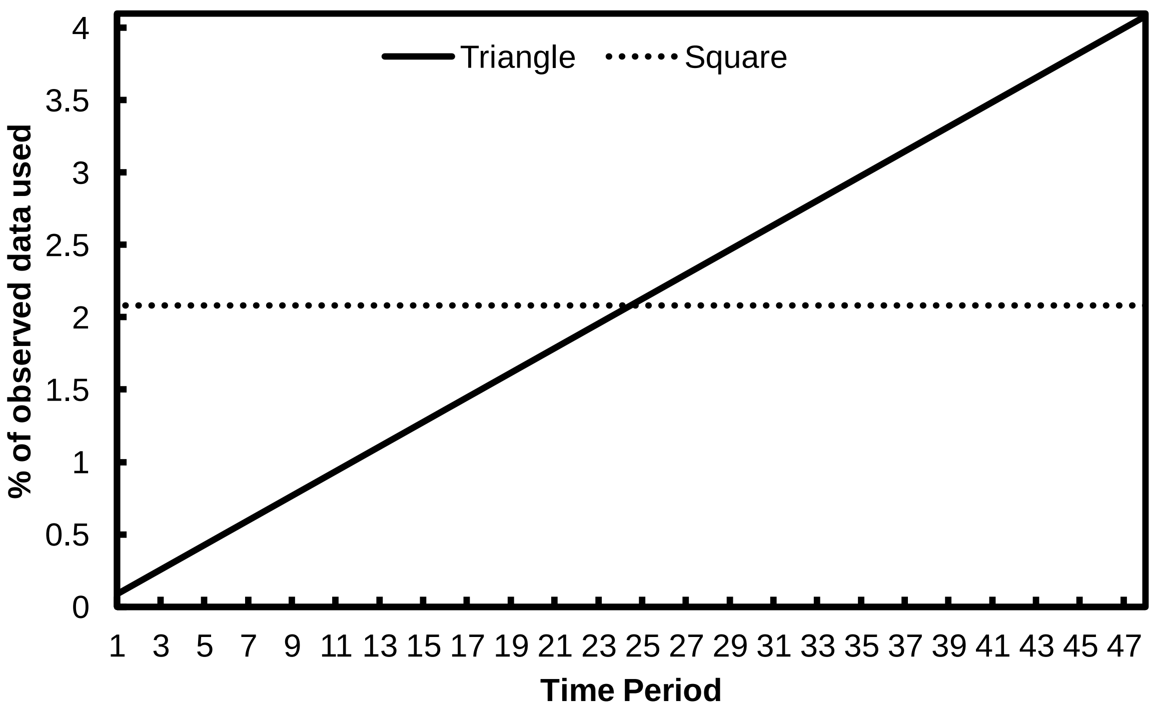


Figure B2: The shape of the triangular and square named filters, with the square filter giving equal weighting at all times and the triangle filter the greatest for the most recent diminishing to very little for the oldest.

It was decided that a filter that follows the shape of a square root function would be investigated (figure B3), as this was similar to the original function, by having higher weighting towards the most recent data, but including more of the older data.

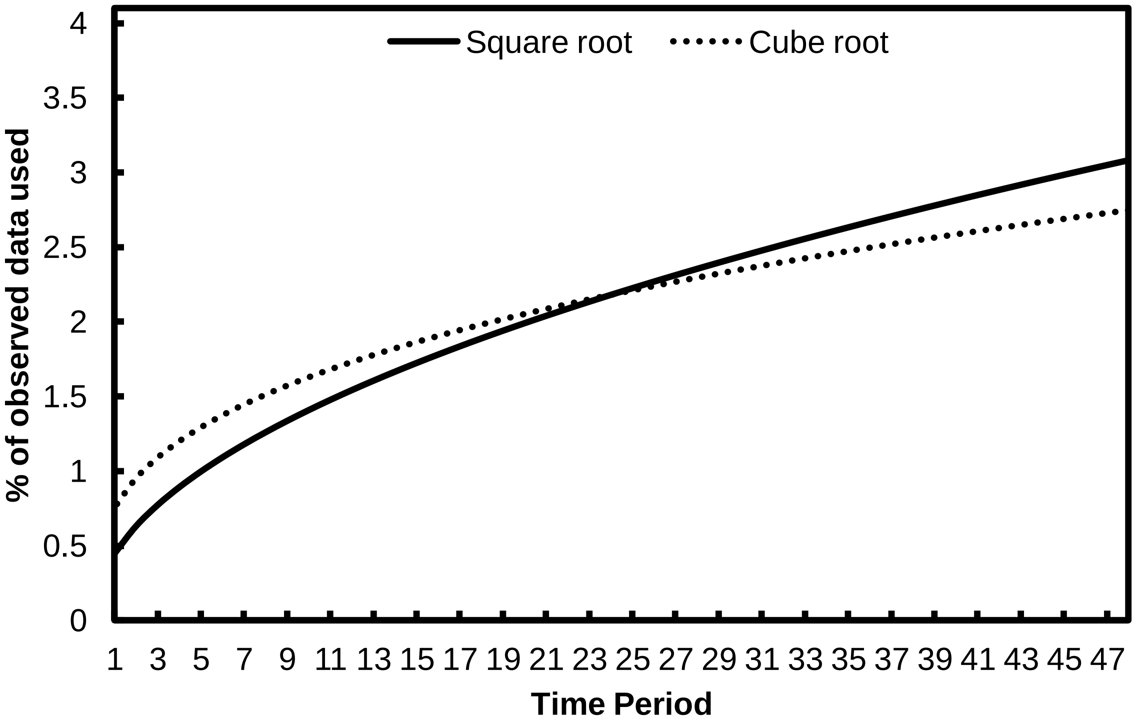


Figure B3: The form of the square root and cube root filters.

Square root filter

This technique for smoothing the data uses a square root function; the form that this gives is plotted in figure B3. Again various lengths of smoothing window were examined, and that which gave the best prediction was 1 day in length. The function is similar to the triangular function in its form, but uses the square root of the value instead of the full value. So for the first period the amount of the original data used is √48/224.96, where 224.96 is the sum of √48+√47+...+√1. Again each of the periods from 1 to 48 are summed to give the smoothed value, which is then processed to predict the indoor relative humidity, the results of which are presented in figure B4. The AWK program for this filter can be found in appendix E.

The correlation coefficient is the same as the previous filter (R^2=0.32), although it is slightly better when not rounded, and again on visual inspection of the graph it is difficult to see any improvement in the prediction. There are still areas where the prediction is significantly different to the observed data.

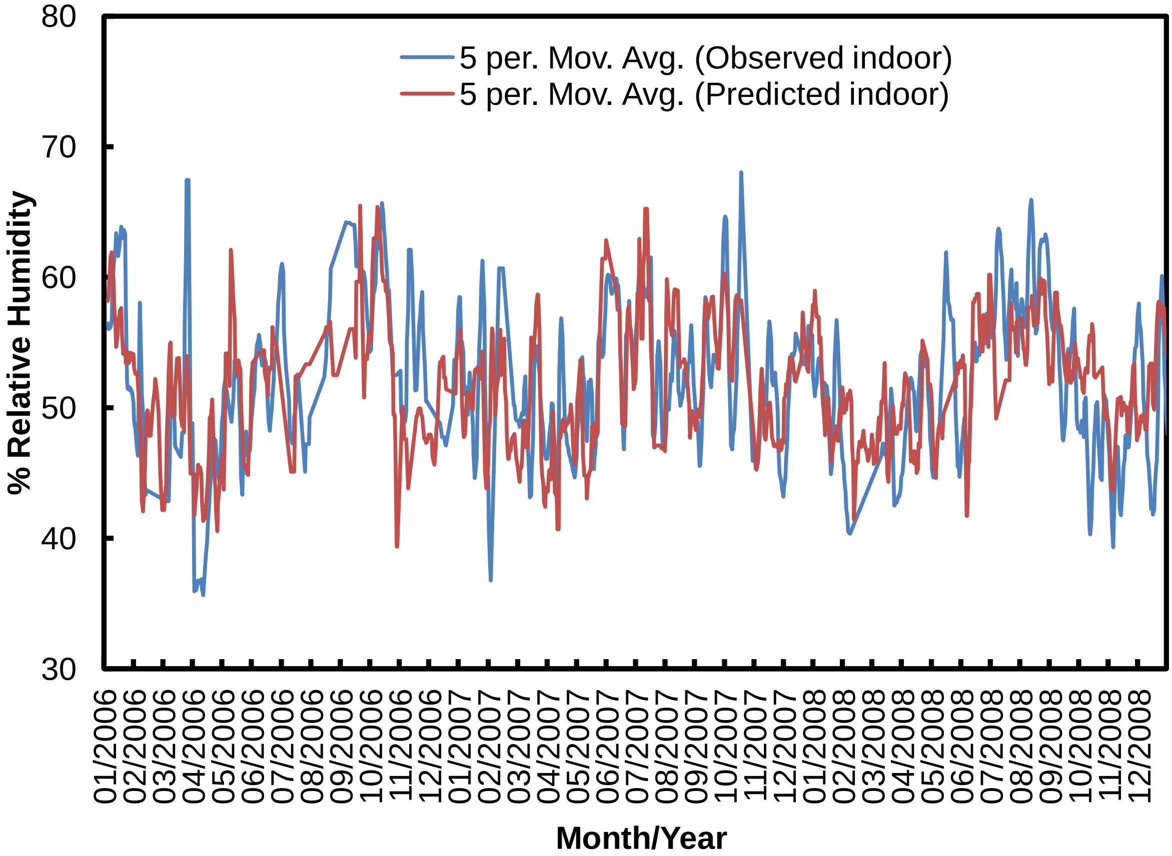


Figure B4: Comparison of predicted and observed indoor relative humidity in the Library at Brodsworth Hall, using the square root filter. Plotted as a 5 day moving average, over the period 01/2006-12/2008.

Cube root filter

It was decided that along with the square root filter a cube root filter would also be implemented, as this would require little extra investigation. The form that this takes can be seen in figure B3. Various lengths of the smoothing window were examined, and again the shorter window was more favourable, at 48 observations. The weighting for each period was calculated according to the following, for period 48, the cube root, here denoted as to the power of a third, was taken for the period and divided by the sum of all of the cube roots (132.37), so (48^(1/3))/132.37, and so on until 1, summing these gives the smoothed value. The AWK program to carry out this smoothing can be found in appendix E. The comparison to the observed relative humidity is not shown as it is very similar to that previously for the square root filter. The correlation coefficient is the same, R^2=0.32, and there are certain areas of the prediction that do not compare well, as has been seen previously.

Confidence intervals

This follows on from section 3.2.8 in chapter 3

Table B1: 95% confidence interval ranges of temperature for the predicted temperature, in the Cartoon Gallery at Knole.

Predicted Temperature	Lower 95% CI	Upper 95% CI	Predicted Temperature	Lower 95% CI	Upper 95% CI
1	-1.87	3.46	**16**	13.39	18.73
2	-0.86	4.48	**17**	14.40	19.74
3	0.16	5.50	**18**	15.42	20.76
4	1.18	6.52	**19**	16.44	21.78
5	2.20	7.53	**20**	17.45	22.80
6	3.21	8.55	**21**	18.47	23.81
7	4.23	9.57	**22**	19.49	24.83
8	5.25	10.59	**23**	20.51	25.85
9	6.26	11.60	**24**	21.52	26.86
10	7.28	12.62	**25**	22.54	27.88
11	8.30	13.64	**26**	23.56	28.90
12	9.32	14.66	**27**	24.58	29.92
13	10.33	15.67	**28**	25.59	30.93
14	11.35	16.69	**29**	26.61	31.95
15	12.37	17.71	**30**	27.63	32.97

Table B2: 95% confidence interval ranges of relative humidity for the predicted relative humidity, in the Cartoon Gallery at Knole.

Predicted Relative Humidity	Lower 95% CI	Upper 95% CI	Predicted Relative Humidity	Lower 95% CI	Upper 95% CI
5	-1.77	24.92	**55**	43.31	69.99
10	2.74	29.43	**60**	47.82	74.50
15	7.25	33.94	**65**	52.32	79.00
20	11.76	38.44	**70**	56.83	83.51
25	16.26	42.95	**75**	61.34	88.02
30	20.77	47.46	**80**	65.85	92.53
35	25.28	51.96	**85**	70.35	97.03
40	29.79	56.47	**90**	74.86	101.54
45	34.29	60.98	**95**	79.37	106.05
50	38.80	65.49	**100**	83.88	110.56

Table B3: 95% confidence interval ranges of temperature for the predicted temperature, in the Great Hall at Canons Ashby.

Predicted Temperature	Lower 95% CI	Upper 95% CI	Predicted Temperature	Lower 95% CI	Upper 95% CI
1	-1.61	3.61	**16**	13.39	18.61
2	-0.61	4.61	**17**	14.39	19.61
3	0.39	5.61	**18**	15.39	20.61
4	1.39	6.61	**19**	16.39	21.61
5	2.39	7.61	**20**	17.39	22.61
6	3.39	8.61	**21**	18.39	23.61
7	4.39	9.61	**22**	19.39	24.61
8	5.39	10.61	**23**	20.39	25.61
9	6.39	11.61	**24**	21.39	26.61
10	7.39	12.61	**25**	22.39	27.61
11	8.39	13.61	**26**	23.39	28.61
12	9.39	14.61	**27**	24.39	29.61
13	10.39	15.61	**28**	25.39	30.61
14	11.39	16.61	**29**	26.39	31.61
15	12.39	17.61	**30**	27.39	32.61

Table B4: 95% confidence interval ranges of relative humidity for the predicted relative humidity, in the Great Hall at Canons Ashby.

Predicted Relative Humidity	Lower 95% CI	Upper 95% CI	Predicted Relative Humidity	Lower 95% CI	Upper 95% CI
5	5.47	23.23	**55**	47.68	65.42
10	9.69	27.45	**60**	51.90	69.64
15	13.91	31.67	**65**	56.12	73.86
20	18.13	35.89	**70**	60.34	78.08
25	22.35	40.12	**75**	64.56	82.30
30	26.57	44.33	**80**	68.78	86.52
35	30.79	48.54	**85**	73.00	90.73
40	35.01	52.76	**90**	77.22	94.95
45	39.24	56.98	**95**	81.44	99.17
50	43.46	61.20	**100**	85.66	103.39

EnergyPlus Simulation Parameters

The simulation parameters of the Brodsworth Hall EnergyPlus model are included here.

Building

North Axis : 45 degrees

Loads Convergence Tolerance Value: 0.04

Temperature Convergence Tolerance Value (delta C): 0.4

Solar Distribution: Minimal Shadowing

Surface Convection Algorithm Inside: Detailed

Surface Convection Algorithm Outside: Detailed

HeatBalanceAlgorithm: Moisture Penetration Depth Conduction Transfer Function

Zone Capacitance Multiplier: 1

Timestep: 1

Run Period

Begin Month: 1

Begin Day of Month: 1

End Month: 12

End Day of Month: 31

Day of Week for Start Day: Sunday

Use Weather File Holidays and Special Days: no

Use Weather File Daylight Saving Period : no

Location and Climate

Site Ground Temperature (Building Surface): 7,7,7,9,11,14,14,14,11,9,7,7 (for each month)

Schedules

Schedule Type Limits

Fraction, range 0.0-1.0, continuous

Temperature, range -20-200, continuous

Control, range 0-4, discrete

Schedule: Day: Hourly

Name: Infiltration day

Type: Fraction

Hours 1-24: 1

Name: Occupied day

Type: Fraction

Hours 1-7 and 19-24: 0

Hours 8-18: 1

Name: off

Type: Fraction

Hours 1-24: 0

Name: Temp

Type: Temperature

Hours 1-24: 40

Name: Con

Type: Control

Hours 1-24: 1

Name: Winter

Type: Fraction

Hours 1-17 &24: 0

Hours 18-23: 1

Name: SprAut

Type: Fraction

Hours 1-19 & 24: 0

Hours 20-23: 0.7

Name: Summer

Type: Fraction

Hours 1-24: 0

Schedule: Week: Daily

Name: Infiltration week

Schedule for all days: Infiltration day

Name: Occupied week

Schedule for all days: occupied day

Name: Off week

Schedule for all days: off

Name: Temp week

Schedule for all days: temp

Name: Con week

Schedule for all days: con

Name: Winter week

Schedule for all days: winter

Name: Spr Aut week

Schedule for all days: Spr Aut

Name: Sum week

Schedule for all days: summer

Schedule: Year

Name: Infiltration

Type: Fraction

Schedule week name: Infiltration week

Start month and day: 1, 1

End month and day: 12, 31

Name: Occupied

Type: Fraction

Schedule week name: Occupied week

Start month and day: 1, 1

End month and day: 12, 31

Name: Heat

Type: Fraction

Schedule week name 1: Infiltration week

Start month and day: 1, 1

End month and day: 3, 31

Schedule week name 2: Off week

Start month and day: 4, 1

End month and day: 9, 30

Schedule week name 3: Infiltration week

Start month and day: 10, 1

End month and day: 12, 31

Name: Off

Type: Fraction

Schedule week name: Off week

Start month and day: 1, 1

End month and day: 12, 31

Name: Day heat

Type: Fraction

Schedule week name 1: Occupied week

Start month and day: 1, 1

End month and day: 4, 30

Schedule week name 2: Off week

Start month and day: 5, 1

End month and day: 8, 31

Schedule week name 3: Occupied week

Start month and day: 9, 1

End month and day: 12, 31

Name: Temp year

Type: Temperature

Schedule week name: Temp week

Start month and day: 1, 1

End month and day: 12, 31

Name: Con year

Type: Control

Schedule week name: Con week

Start month and day: 1, 1

End month and day: 12, 31

Name: Sced1

Type: Fraction

Schedule week name 1: Winter Week

Start month and day: 1, 1

End month and day: 2, 28

Schedule week name 2: Spr Aut Week

Start month and day: 3, 1

End month and day: 5, 31

Schedule week name 3: Sum Week

Start month and day: 6, 1

End month and day: 8, 31

Schedule week name 4: Spr Aut Week

Start month and day: 9, 1

End month and day: 11, 30

Schedule week name 5: Winter Week

Start month and day: 12, 1

End month and day: 12, 31

Material

Stone, !- Name

Rough, !- Roughness

0.45, !- Thickness {m}

1.79, !- Conductivity {W/m-K}

881, !- Density {kg/m3}

1670, !- Specific Heat {J/kg-K}

0.9, !- Thermal Absorptance

0.7, !- Solar Absorptance

0.7; !- Visible Absorptance

Brick, !- Name

Rough, !- Roughness

```
0.1,                    !- Thickness {m}
1.33,                   !- Conductivity {W/m-K}
2002,                   !- Density {kg/m3}
920,                    !- Specific Heat {J/kg-K}
0.9,                    !- Thermal Absorptance
0.93,                   !- Solar Absorptance
0.93;                   !- Visible Absorptance

Plaster,                !- Name
Smooth,                 !- Roughness
0.02,                   !- Thickness {m}
0.69,                   !- Conductivity {W/m-K}
1858,                   !- Density {kg/m3}
830,                    !- Specific Heat {J/kg-K}
0.9,                    !- Thermal Absorptance
0.7,                    !- Solar Absorptance
0.7;                    !- Visible Absorptance

Slate,                  !- Name
MediumSmooth,           !- Roughness
0.001,                  !- Thickness {m}
1.44,                   !- Conductivity {W/m-K}
1600,                   !- Density {kg/m3}
1460,                   !- Specific Heat {J/kg-K}
0.9,                    !- Thermal Absorptance
0.7,                    !- Solar Absorptance
0.7;                    !- Visible Absorptance
```

Beam, !- Name

MediumRough, !- Roughness

0.1, !- Thickness {m}

0.12, !- Conductivity {W/m-K}

592, !- Density {kg/m3}

2510, !- Specific Heat {J/kg-K}

0.9, !- Thermal Absorptance

0.7, !- Solar Absorptance

0.7; !- Visible Absorptance

Flag, !- Name

Rough, !- Roughness

0.03, !- Thickness {m}

1.79, !- Conductivity {W/m-K}

881, !- Density {kg/m3}

1670, !- Specific Heat {J/kg-K}

0.9, !- Thermal Absorptance

0.7, !- Solar Absorptance

0.7; !- Visible Absorptance

Window Material: Glazing,

Single Pane, !- Name

SpectralAverage, !- Optical Data Type

, !- Window Glass Spectral Data Set Name

0.003, !- Thickness {m}

0.9, !- Solar Transmittance at Normal Incidence

0.031, !- Front Side Solar Reflectance at Normal Incidence

0.031, !- Back Side Solar Reflectance at Normal Incidence

0.9, !- Visible Transmittance at Normal Incidence

0.05, !- Front Side Visible Reflectance at Normal Incidence

0.05, !- Back Side Visible Reflectance at Normal Incidence

0, !- Infrared Transmittance at Normal Incidence

0.84, !- Front Side Infrared Hemispherical Emissivity

0.84, !- Back Side Infrared Hemispherical Emissivity

0.9; !- Conductivity {W/m-K}

Window Material: Shade,

HIGH REFLECT - LOW TRANS SHADE, !- Name

0.1, !- Solar Transmittance

0.8, !- Solar Reflectance

0.1, !- Visible Transmittance

0.8, !- Visible Reflectance

0.9, !- Thermal Hemispherical Emissivity

0.0, !- Thermal Transmittance

0.005, !- Thickness {m}

0.1, !- Conductivity {W/m-K}

0.05, !- Shade to Glass Distance {m}

0.5, !- Top Opening Multiplier

0.5, !- Bottom Opening Multiplier

0.5, !- Left-Side Opening Multiplier

0.5, !- Right-Side Opening Multiplier

0.0; !- Airflow Permeability

Material Property: Moisture Penetration Depth: Settings

Plaster, !- Name

0.0005, !- Moisture Penetration Depth {m}

0.001, !- Moisture Equation Coefficient a {dimensionless}

0.397173, !- Moisture Equation Coefficient b {dimensionless}

0.001, !- Moisture Equation Coefficient c {dimensionless}

11.7057; !- Moisture Equation Coefficient d {dimensionless}

Beam, !- Name

0.0005, !- Moisture Penetration Depth {m}

0.144687, !- Moisture Equation Coefficient a {dimensionless}

0.631307, !- Moisture Equation Coefficient b {dimensionless}

0.122495, !- Moisture Equation Coefficient c {dimensionless}

10.1203; !- Moisture Equation Coefficient d {dimensionless}

Flag, !- Name

0.0005, !- Moisture Penetration Depth {m}

0.01385, !- Moisture Equation Coefficient a {dimensionless}

9.638, !- Moisture Equation Coefficient b {dimensionless}

0.02462, !- Moisture Equation Coefficient c {dimensionless}

0.6763; !- Moisture Equation Coefficient d {dimensionless}

Construction

Wall, !- Name

Stone, !- Outside Layer

Brick, !- Layer 2

Plaster; !- Layer 3

Floor, !- Name

Flag; !- Outside Layer

Window, !- Name

Single Pane; !- Outside Layer

Roof, !- Name

slate, !- Outside Layer

Beam; !- Layer 2

IntWall, !- Name

Plaster, !- Outside Layer

Brick, !- Layer 2

Plaster; !- Layer 3

Global Geometry Rules

UpperLeftCorner, !- Starting Vertex Position

Counterclockwise, !- Vertex Entry Direction

WorldCoordinateSystem; !- Coordinate System

Zone

Basement, !- Name

0, !- Direction of Relative North {deg}

0, 0, 0, !- X,Y,Z {m}

1, !- Type

1, !- Multiplier

```
3,                      !- Ceiling Height {m}
0;                      !- Volume {m3}

Ground,                 !- Name
0,                      !- Direction of Relative North {deg}
0, 0, 0,                !- X,Y,Z  {m}
1,                      !- Type
1,                      !- Multiplier
5,                      !- Ceiling Height {m}
0;                      !- Volume {m3}

First,                  !- Name
0,                      !- Direction of Relative North {deg}
0, 0, 0,                !- X,Y,Z  {m}
1,                      !- Type
1,                      !- Multiplier
5,                      !- Ceiling Height {m}
0;                      !- Volume {m3}

Library,                !- Name
0,                      !- Direction of Relative North {deg}
0, 0, 0,                !- X,Y,Z  {m}
1,                      !- Type
1,                      !- Multiplier
5,                      !- Ceiling Height {m}
0;                      !- Volume {m3}
```

Building Surface: Detailed

```
Base1,              !- Name
Wall,               !- Surface Type
Wall,               !- Construction Name
Basement,           !- Zone Name
Ground,             !- Outside Boundary Condition
,                   !- Outside Boundary Condition Object
NoSun,              !- Sun Exposure
NoWind,             !- Wind Exposure
,                   !- View Factor to Ground
4,                  !- Number of Vertices
0, 25, 3,           !- X,Y,Z  1 {m}
0, 25, 0,           !- X,Y,Z  2 {m}
0, 0, 0,            !- X,Y,Z  3 {m}
0, 0, 3;            !- X,Y,Z  4 {m}

Base2,              !- Name
Wall,               !- Surface Type
Wall,               !- Construction Name
Basement,           !- Zone Name
Ground,             !- Outside Boundary Condition
,                   !- Outside Boundary Condition Object
NoSun,              !- Sun Exposure
NoWind,             !- Wind Exposure
,                   !- View Factor to Ground
4,                  !- Number of Vertices
0, 0, 3,            !- X,Y,Z  1 {m}
```

```
0, 0, 0,                    !- X,Y,Z  2 {m}

50, 0, 0,                   !- X,Y,Z  3 {m}

50, 0, 3;                   !- X,Y,Z  4 {m}


Base3,              !- Name

Wall,               !- Surface Type

Wall,               !- Construction Name

Basement,           !- Zone Name

Ground,             !- Outside Boundary Condition

,                   !- Outside Boundary Condition Object

NoSun,              !- Sun Exposure

NoWind,             !- Wind Exposure

,                   !- View Factor to Ground

4,                  !- Number of Vertices

50, 0, 3,                   !- X,Y,Z  1 {m}

50, 0, 0,                   !- X,Y,Z  2 {m}

50, 25, 0,                  !- X,Y,Z  3 {m}

50, 25, 3;                  !- X,Y,Z  4 {m}


Base4,              !- Name

Wall,               !- Surface Type

Wall,               !- Construction Name

Basement,           !- Zone Name

Ground,             !- Outside Boundary Condition

,                   !- Outside Boundary Condition Object

NoSun,              !- Sun Exposure

NoWind,             !- Wind Exposure
```

```
,                    !- View Factor to Ground
4,                   !- Number of Vertices
50, 25, 3,                  !- X,Y,Z  1 {m}
50, 25, 0,                  !- X,Y,Z  2 {m}
0, 25, 0,                   !- X,Y,Z  3 {m}
0, 25, 3;                   !- X,Y,Z  4 {m}

BaseFloor,           !- Name
Floor,               !- Surface Type
Floor,               !- Construction Name
Basement,            !- Zone Name
Ground,              !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
NoSun,               !- Sun Exposure
NoWind,              !- Wind Exposure
,                    !- View Factor to Ground
4,                   !- Number of Vertices
0, 0, 0,                    !- X,Y,Z  1 {m}
0, 25, 0,                   !- X,Y,Z  2 {m}
50, 25, 0,                  !- X,Y,Z  3 {m}
50, 0, 0;                   !- X,Y,Z  4 {m}

BaseCeil_lib,        !- Name
Ceiling,             !- Surface Type
Floor,               !- Construction Name
Basement,            !- Zone Name
Surface,             !- Outside Boundary Condition
```

```
LibFloor,              !- Outside Boundary Condition Object
NoSun,                 !- Sun Exposure
NoWind,                !- Wind Exposure
,                      !- View Factor to Ground
4,                     !- Number of Vertices
0, 8, 3,                    !- X,Y,Z  1 {m}
8, 8, 3,                    !- X,Y,Z  2 {m}
8, 16, 3,                   !- X,Y,Z  3 {m}
0, 16, 3;                   !- X,Y,Z  4 {m}

BaseCeil_ground,       !- Name
Ceiling,               !- Surface Type
Floor,                 !- Construction Name
Basement,              !- Zone Name
Surface,               !- Outside Boundary Condition
GroundFloor,           !- Outside Boundary Condition Object
NoSun,                 !- Sun Exposure
NoWind,                !- Wind Exposure
,                      !- View Factor to Ground
8,                     !- Number of Vertices
0, 0, 3,                    !- X,Y,Z  1 {m}
50, 0, 3,                   !- X,Y,Z  2 {m}
50, 25, 3,                  !- X,Y,Z  3 {m}
0, 25, 3,                   !- X,Y,Z  4 {m}
0, 16, 3,                   !- X,Y,Z  5 {m}
8, 16, 3,                   !- X,Y,Z  6 {m}
8, 8, 3,                    !- X,Y,Z  7 {m}
```

```
0, 8, 3;                        !- X,Y,Z  8 {m}

Lib1,                 !- Name
Wall,                 !- Surface Type
Wall,                 !- Construction Name
Library,              !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
0, 16, 8,                       !- X,Y,Z  1 {m}
0, 16, 3,                       !- X,Y,Z  2 {m}
0, 8, 3,                        !- X,Y,Z  3 {m}
0, 8, 8;                        !- X,Y,Z  4 {m}

Lib2,                 !- Name
Wall,                 !- Surface Type
IntWall,              !- Construction Name
Library,              !- Zone Name
Surface,              !- Outside Boundary Condition
Ground2,              !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
```

```
8, 16, 8,               !- X,Y,Z  1 {m}
8, 16, 3,               !- X,Y,Z  2 {m}
0, 16, 3,               !- X,Y,Z  3 {m}
0, 16, 8;               !- X,Y,Z  4 {m}

Lib3,             !- Name
Wall,             !- Surface Type
IntWall,          !- Construction Name
Library,          !- Zone Name
Surface,          !- Outside Boundary Condition
Ground3,          !- Outside Boundary Condition Object
NoSun,            !- Sun Exposure
NoWind,           !- Wind Exposure
,                 !- View Factor to Ground
4,                !- Number of Vertices
8, 8, 8,                !- X,Y,Z  1 {m}
8, 8, 3,                !- X,Y,Z  2 {m}
8, 16, 3,               !- X,Y,Z  3 {m}
8, 16, 8;               !- X,Y,Z  4 {m}

Lib4,             !- Name
Wall,             !- Surface Type
IntWall,          !- Construction Name
Library,          !- Zone Name
Surface,          !- Outside Boundary Condition
Ground4,          !- Outside Boundary Condition Object
NoSun,            !- Sun Exposure
```

```
NoWind,                !- Wind Exposure
,                      !- View Factor to Ground
4,                     !- Number of Vertices
0, 8, 8,                      !- X,Y,Z  1 {m}
0, 8, 3,                      !- X,Y,Z  2 {m}
8, 8, 3,                      !- X,Y,Z  3 {m}
8, 8, 8;                      !- X,Y,Z  4 {m}

LibFloor,              !- Name
Floor,                 !- Surface Type
Floor,                 !- Construction Name
Library,               !- Zone Name
Surface,               !- Outside Boundary Condition
BaseCeil_lib,          !- Outside Boundary Condition Object
NoSun,                 !- Sun Exposure
NoWind,                !- Wind Exposure
,                      !- View Factor to Ground
4,                     !- Number of Vertices
0, 8, 3,                      !- X,Y,Z  1 {m}
0, 16, 3,                     !- X,Y,Z  2 {m}
8, 16, 3,                     !- X,Y,Z  3 {m}
8, 8, 3;                      !- X,Y,Z  4 {m}

LibCeil,               !- Name
Ceiling,               !- Surface Type
Floor,                 !- Construction Name
Library,               !- Zone Name
```

```
Surface,                !- Outside Boundary Condition
FirstFloorLib,          !- Outside Boundary Condition Object
NoSun,                  !- Sun Exposure
NoWind,                 !- Wind Exposure
,                       !- View Factor to Ground
4,                      !- Number of Vertices
0, 8, 8,                      !- X,Y,Z  1 {m}
8, 8, 8,                      !- X,Y,Z  2 {m}
8, 16, 8,                     !- X,Y,Z  3 {m}
0, 16, 8;                     !- X,Y,Z  4 {m}

Ground1,                !- Name
Wall,                   !- Surface Type
Wall,                   !- Construction Name
Ground,                 !- Zone Name
Outdoors,               !- Outside Boundary Condition
,                       !- Outside Boundary Condition Object
SunExposed,             !- Sun Exposure
WindExposed,            !- Wind Exposure
,                       !- View Factor to Ground
4,                      !- Number of Vertices
0, 25, 8,                     !- X,Y,Z  1 {m}
0, 25, 3,                     !- X,Y,Z  2 {m}
0, 16, 3,                     !- X,Y,Z  3 {m}
0, 16, 8;                     !- X,Y,Z  4 {m}

Ground2,                !- Name
```

```
Wall,                !- Surface Type
IntWall,             !- Construction Name
Ground,              !- Zone Name
Surface,             !- Outside Boundary Condition
Lib2,                !- Outside Boundary Condition Object
NoSun,               !- Sun Exposure
NoWind,              !- Wind Exposure
,                    !- View Factor to Ground
4,                   !- Number of Vertices
0, 16, 8,                  !- X,Y,Z  1 {m}
0, 16, 3,                  !- X,Y,Z  2 {m}
8, 16, 3,                  !- X,Y,Z  3 {m}
8, 16, 8;                  !- X,Y,Z  4 {m}

Ground3,             !- Name
Wall,                !- Surface Type
IntWall,             !- Construction Name
Ground,              !- Zone Name
Surface,             !- Outside Boundary Condition
Lib3,                !- Outside Boundary Condition Object
NoSun,               !- Sun Exposure
NoWind,              !- Wind Exposure
,                    !- View Factor to Ground
4,                   !- Number of Vertices
8, 16, 8,                  !- X,Y,Z  1 {m}
8, 16, 3,                  !- X,Y,Z  2 {m}
8, 8, 3,                   !- X,Y,Z  3 {m}
```

```
8, 8, 8;                    !- X,Y,Z  4 {m}

Ground4,              !- Name
Wall,                 !- Surface Type
IntWall,              !- Construction Name
Ground,               !- Zone Name
Surface,              !- Outside Boundary Condition
Lib4,                 !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
8, 8, 8,                    !- X,Y,Z  1 {m}
8, 8, 3,                    !- X,Y,Z  2 {m}
0, 8, 3,                    !- X,Y,Z  3 {m}
0, 8, 8;                    !- X,Y,Z  4 {m}

Ground5,              !- Name
Wall,                 !- Surface Type
Wall,                 !- Construction Name
Ground,               !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
```

```
0, 8, 8,                !- X,Y,Z  1 {m}
0, 8, 3,                !- X,Y,Z  2 {m}
0, 0, 3,                !- X,Y,Z  3 {m}
0, 0, 8;                !- X,Y,Z  4 {m}

Ground6,           !- Name
Wall,              !- Surface Type
Wall,              !- Construction Name
Ground,            !- Zone Name
Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
WindExposed,       !- Wind Exposure
,                  !- View Factor to Ground
4,                 !- Number of Vertices
0, 0, 8,                !- X,Y,Z  1 {m}
0, 0, 3,                !- X,Y,Z  2 {m}
50, 0, 3,               !- X,Y,Z  3 {m}
50, 0, 8;               !- X,Y,Z  4 {m}

Ground7,           !- Name
Wall,              !- Surface Type
Wall,              !- Construction Name
Ground,            !- Zone Name
Outdoors,          !- Outside Boundary Condition
,                  !- Outside Boundary Condition Object
SunExposed,        !- Sun Exposure
```

```
WindExposed,            !- Wind Exposure
,                       !- View Factor to Ground
4,                      !- Number of Vertices
50, 0, 8,                       !- X,Y,Z  1 {m}
50, 0, 3,                       !- X,Y,Z  2 {m}
50, 25, 3,                      !- X,Y,Z  3 {m}
50, 25, 8;                      !- X,Y,Z  4 {m}

Ground8,                !- Name
Wall,                   !- Surface Type
Wall,                   !- Construction Name
Ground,                 !- Zone Name
Outdoors,               !- Outside Boundary Condition
,                       !- Outside Boundary Condition Object
SunExposed,             !- Sun Exposure
WindExposed,            !- Wind Exposure
,                       !- View Factor to Ground
4,                      !- Number of Vertices
50, 25, 8,                      !- X,Y,Z  1 {m}
50, 25, 3,                      !- X,Y,Z  2 {m}
0, 25, 3,                       !- X,Y,Z  3 {m}
0, 25, 8;                       !- X,Y,Z  4 {m}

GroundFloor,            !- Name
Floor,                  !- Surface Type
Floor,                  !- Construction Name
Ground,                 !- Zone Name
```

Surface, !- Outside Boundary Condition

BaseCeil_ground, !- Outside Boundary Condition Object

NoSun, !- Sun Exposure

NoWind, !- Wind Exposure

, !- View Factor to Ground

8, !- Number of Vertices

0, 0, 3, !- X,Y,Z 1 {m}

0, 8, 3, !- X,Y,Z 2 {m}

8, 8, 3, !- X,Y,Z 3 {m}

8, 16, 3, !- X,Y,Z 4 {m}

0, 16, 3, !- X,Y,Z 5 {m}

0, 25, 3, !- X,Y,Z 6 {m}

50, 25, 3, !- X,Y,Z 7 {m}

50, 0, 3; !- X,Y,Z 8 {m}

First1, !- Name

Wall, !- Surface Type

Wall, !- Construction Name

First, !- Zone Name

Outdoors, !- Outside Boundary Condition

, !- Outside Boundary Condition Object

SunExposed, !- Sun Exposure

WindExposed, !- Wind Exposure

, !- View Factor to Ground

4, !- Number of Vertices

0, 25, 13, !- X,Y,Z 1 {m}

0, 25, 8, !- X,Y,Z 2 {m}

```
0, 0, 8,                    !- X,Y,Z  3 {m}
0, 0, 13;                   !- X,Y,Z  4 {m}

First2,              !- Name
Wall,                !- Surface Type
Wall,                !- Construction Name
First,               !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
4,                   !- Number of Vertices
0, 0, 13,                   !- X,Y,Z  1 {m}
0, 0, 8,                    !- X,Y,Z  2 {m}
50, 0, 8,                   !- X,Y,Z  3 {m}
50, 0, 13;                  !- X,Y,Z  4 {m}

First3,              !- Name
Wall,                !- Surface Type
Wall,                !- Construction Name
First,               !- Zone Name
Outdoors,            !- Outside Boundary Condition
,                    !- Outside Boundary Condition Object
SunExposed,          !- Sun Exposure
WindExposed,         !- Wind Exposure
,                    !- View Factor to Ground
```

```
4,                    !- Number of Vertices
50, 0, 13,                    !- X,Y,Z  1 {m}
50, 0, 8,                     !- X,Y,Z  2 {m}
50, 25, 8,                    !- X,Y,Z  3 {m}
50, 25, 13;                   !- X,Y,Z  4 {m}

First4,               !- Name
Wall,                 !- Surface Type
Wall,                 !- Construction Name
First,                !- Zone Name
Outdoors,             !- Outside Boundary Condition
,                     !- Outside Boundary Condition Object
SunExposed,           !- Sun Exposure
WindExposed,          !- Wind Exposure
,                     !- View Factor to Ground
4,                    !- Number of Vertices
50, 25, 13,                   !- X,Y,Z  1 {m}
50, 25, 8,                    !- X,Y,Z  2 {m}
0, 25, 8,                     !- X,Y,Z  3 {m}
0, 25, 13;                    !- X,Y,Z  4 {m}

FirstFloorLib,        !- Name
Floor,                !- Surface Type
Floor,                !- Construction Name
First,                !- Zone Name
Surface,              !- Outside Boundary Condition
LibCeil,              !- Outside Boundary Condition Object
```

```
NoSun,                   !- Sun Exposure
NoWind,                  !- Wind Exposure
,                        !- View Factor to Ground
4,                       !- Number of Vertices
0, 8, 8,                            !- X,Y,Z  1 {m}
0, 16, 8,                           !- X,Y,Z  2 {m}
8, 16, 8,                           !- X,Y,Z  3 {m}
8, 8, 8;                            !- X,Y,Z  4 {m}

FirstRoof,               !- Name
Roof,                    !- Surface Type
Roof,                    !- Construction Name
First,                   !- Zone Name
Outdoors,                !- Outside Boundary Condition
,                        !- Outside Boundary Condition Object
SunExposed,              !- Sun Exposure
WindExposed,             !- Wind Exposure
,                        !- View Factor to Ground
4,                       !- Number of Vertices
0, 0, 13,                           !- X,Y,Z  1 {m}
50, 0, 13,                          !- X,Y,Z  2 {m}
50, 25, 13,                         !- X,Y,Z  3 {m}
0, 25, 13;                          !- X,Y,Z  4 {m}

FirstFloorGround,        !- Name
Floor,                   !- Surface Type
Floor,                   !- Construction Name
```

```
Ground,               !- Zone Name
Surface,              !- Outside Boundary Condition
GroundCeiling,        !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
,                     !- View Factor to Ground
8,                    !- Number of Vertices
0, 0, 8,              !- X,Y,Z  1 {m}
0, 8, 8,              !- X,Y,Z  2 {m}
8, 8, 8,              !- X,Y,Z  3 {m}
8, 16, 8,             !- X,Y,Z  4 {m}
0, 16, 8,             !- X,Y,Z  5 {m}
0, 25, 8,             !- X,Y,Z  6 {m}
50, 25, 8,            !- X,Y,Z  7 {m}
50, 0, 8;             !- X,Y,Z  8 {m}

GoundCeiling,         !- Name
Ceiling,              !- Surface Type
Floor,                !- Construction Name
Basement,             !- Zone Name
Surface,              !- Outside Boundary Condition
FirstFloorGround,     !- Outside Boundary Condition Object
NoSun,                !- Sun Exposure
NoWind,               !- Wind Exposure
,                     !- View Factor to Ground
8,                    !- Number of Vertices
0, 0, 8,              !- X,Y,Z  1 {m}
```

```
50, 0, 8,                    !- X,Y,Z  2 {m}
50, 25, 8,                   !- X,Y,Z  3 {m}
0, 25, 8,                    !- X,Y,Z  4 {m}
0, 16, 8,                    !- X,Y,Z  5 {m}
8, 16, 8,                    !- X,Y,Z  6 {m}
8, 8, 8,                     !- X,Y,Z  7 {m}
0, 8, 8;                     !- X,Y,Z  8 {m}
```

Fenestration Surface: Detailed

```
libwin,               !- Name
Window,               !- Surface Type
Window,               !- Construction Name
Lib1,                 !- Building Surface Name
,                     !- Outside Boundary Condition Object
,                     !- View Factor to Ground
LibWindow,            !- Shading Control Name
,                     !- Frame and Divider Name
1,                    !- Multiplier
4,                    !- Number of Vertices
0, 12, 7,                    !- X,Y,Z  1 {m}
0, 12, 4,                    !- X,Y,Z  2 {m}
0, 10, 4,                    !- X,Y,Z  3 {m}
0, 10, 7;                    !- X,Y,Z  4 {m}
```

Window Property: Shading Control

```
LibWindow,            !- Name
InteriorShade,        !- Shading Type
```

```
,                    !- Construction with Shading Name
AlwaysOn,            !- Shading Control Type
,                    !- Schedule Name
,                    !- Setpoint {W/m2, W or deg C}
,                    !- Shading Control Is Scheduled
,                    !- Glare Control Is Active
HIGH REFLECT - LOW TRANS SHADE,  !- Shading Device Material Name
,                    !- Type of Slat Angle Control for Blinds
;                    !- Slat Angle Schedule Name
```

Electric Equipment,

```
BasementGain,        !- Name
Basement,            !- Zone Name
Dayheat,             !- Schedule Name
EquipmentLevel,      !- Design Level Calculation Method
20000,               !- Design Level {W}
,                    !- Watts per Zone Floor Area {W/m2}
,                    !- Watts per Person {W/person}
0,                   !- Fraction Latent
0;                   !- Fraction Radiant

LibraryGain,         !- Name
Library,             !- Zone Name
Off,                 !- Schedule Name
EquipmentLevel,      !- Design Level Calculation Method
0,                   !- Design Level {W}
,                    !- Watts per Zone Floor Area {W/m2}
```

```
,                     !- Watts per Person {W/person}
0,                    !- Fraction Latent
0;                    !- Fraction Radiant

FirstGain,            !- Name
First,                !- Zone Name
Dayheat,              !- Schedule Name
EquipmentLevel,       !- Design Level Calculation Method
30000,                !- Design Level {W}
,                     !- Watts per Zone Floor Area {W/m2}
,                     !- Watts per Person {W/person}
0,                    !- Fraction Latent
0;                    !- Fraction Radiant

GroundGain,           !- Name
Ground,               !- Zone Name
Dayheat,              !- Schedule Name
EquipmentLevel,       !- Design Level Calculation Method
20000,                !- Design Level {W}
,                     !- Watts per Zone Floor Area {W/m2}
,                     !- Watts per Person {W/person}
0,                    !- Fraction Latent
0;                    !- Fraction Radiant
```

Other Equipment

```
BasementMoist,        !- Name
Basement,             !- Zone Name
```

```
Off,                !- Schedule Name
EquipmentLevel,         !- Design Level Calculation Method
500,                !- Design Level {W}
,                   !- Watts per Zone Floor Area {W/m2}
,                   !- Watts per Person {W/Person}
1;                  !- Fraction Latent

LibrayMoist,            !- Name
Library,            !- Zone Name
Off,                !- Schedule Name
EquipmentLevel,         !- Design Level Calculation Method
500,                !- Design Level {W}
,                   !- Watts per Zone Floor Area {W/m2}
,                   !- Watts per Person {W/Person}
1;                  !- Fraction Latent

FirstMoist,             !- Name
First,              !- Zone Name
Off,                !- Schedule Name
EquipmentLevel,         !- Design Level Calculation Method
500,                !- Design Level {W}
,                   !- Watts per Zone Floor Area {W/m2}
,                   !- Watts per Person {W/Person}
1;                  !- Fraction Latent

GroundMoist,            !- Name
Ground,             !- Zone Name
```

```
Off,                    !- Schedule Name
EquipmentLevel,         !- Design Level Calculation Method
500,                    !- Design Level {W}
,                       !- Watts per Zone Floor Area {W/m2}
,                       !- Watts per Person {W/Person}
1;                      !- Fraction Latent
```

Zone Infiltration

```
BasementINF,            !- Name
Basement,               !- Zone Name
Infiltration,           !- Schedule Name
Flow/Zone,              !- Design Flow Rate Calculation Method
0.15,                   !- Design Flow Rate {m3/s}
,                       !- Flow per Zone Floor Area {m3/s-m2}
,                       !- Flow per Exterior Surface Area {m3/s-m2}
,                       !- Air Changes per Hour
1,                      !- Constant Term Coefficient
0,                      !- Temperature Term Coefficient
0,                      !- Velocity Term Coefficient
;                       !- Velocity Squared Term Coefficient

GroundINF,              !- Name
Ground,                 !- Zone Name
Infiltration,           !- Schedule Name
Flow/Zone,              !- Design Flow Rate Calculation Method
0.3,                    !- Design Flow Rate {m3/s}
,                       !- Flow per Zone Floor Area {m3/s-m2}
```

```
,                    !- Flow per Exterior Surface Area {m3/s-m2}
,                    !- Air Changes per Hour
1,                   !- Constant Term Coefficient
0,                   !- Temperature Term Coefficient
0,                   !- Velocity Term Coefficient
;                    !- Velocity Squared Term Coefficient

FirstINF,            !- Name
First,               !- Zone Name
Infiltration,        !- Schedule Name
Flow/Zone,           !- Design Flow Rate Calculation Method
0.3,                 !- Design Flow Rate {m3/s}
,                    !- Flow per Zone Floor Area {m3/s-m2}
,                    !- Flow per Exterior Surface Area {m3/s-m2}
,                    !- Air Changes per Hour
1,                   !- Constant Term Coefficient
0,                   !- Temperature Term Coefficient
0,                   !- Velocity Term Coefficient
;                    !- Velocity Squared Term Coefficient

LibraryINF,          !- Name
Library,             !- Zone Name
Infiltration,        !- Schedule Name
Flow/Zone,           !- Design Flow Rate Calculation Method
0.05,                !- Design Flow Rate {m3/s}
,                    !- Flow per Zone Floor Area {m3/s-m2}
,                    !- Flow per Exterior Surface Area {m3/s-m2}
```

,   !- Air Changes per Hour

1,   !- Constant Term Coefficient

0,   !- Temperature Term Coefficient

0,   !- Velocity Term Coefficient

;   !- Velocity Squared Term Coefficient

Report outputs

Output:Variable,*,Outdoor Dry Bulb,Hourly;

Output:Variable,*,Outdoor Relative Humidity,Hourly;

Output:Variable,*,Zone Total Internal Radiant Heat Gain ,Hourly;

Output:Variable,*,Zone Mean Air Temperature,Hourly;

Output:Variable,*,Zone Air Relative Humidity ,Hourly;

APPENDIX C

EUROPE RESULTS

Damage Results

The isoperm

The results for the isoperm damage function are shown in figure C1, and show some agreement with the results of the previous paper damage function.

TWPI

The projected impact that climate change will have on the relative degradation rate of paper, as estimated using the TWPI damage function is shown in figure C2. As shown with the previous paper functions the rate is expected to increase for all of the seven locations.

Hukka

The projections of future mould growth across the European locations for this damage function are presented in figure C3. There is good agreement with the results of the Isaksson et al (2010) function, although the magnitude is somewhat larger here, a maximum of 30 compared to 8 days of mould risk. Although it appears quite dramatic towards the end of the century, it is not every year that mould growth is projected. The mould growth model works in a way that builds up to mould germination, thus prolonged periods of ideal conditions are required, which is projected to occur some years and not others.

Salt transitions – 60%

The results of one of the generalised salt transition models are presented in figure C4a and b, split for clarity. If such a salt mixture with a critical humidity at 60% realtive humidity existed it is projected that transitions would increase at Sevenoaks, Oviedo and Paris. A slight increase in transitions is projected for Leon and Prague, again difficult to determine from the natural variation. The projection for Doncaster shows no change over the coming century, from the baseline, while Almeria indicates a decrease in transitions. This corresponds with the drop in humidity projected for Almeria, the average baseline realtive humidity is approxamelty 64%, thus the data would flucutaute around this and cross 60%, in the future the average drops to below 60%, whilst there are still fluctuations taking the average above 60%, they have decreased.

This technique higlights how it is possible, should the composition of salts be determined, and thus the critical humidity, that it is possible to then apply the method presented in this work and project how the transitions will change in the future. This will help inform the decisions taken to mitigate the damage.

Salt transitions – 85%

The results of the projected impact of climate change on 85% relative humidity transitions are shown in figures C5a and b, again split for clarity. Across all seven locations it is projected that there is an increase in transitions in the future.

10% Humidity shock

Another classification used by Michalski (1996) is that of 10% relative humidity fluctuations. This can either be defined as (a) possible fracture for each occurrence in relation to objects of a very high vulnerability, or (b) gradual fatigue fracture for highly vulnerable objects. The projections of the impact of climate change for this damage function are shown in figures C6a and b. As with the 5% analysis all locations are projected to have an increase in damaging events, with the exception of Almeria, which shows no noticeable change.

20% Humidity shock

The third classification used by Michalski (1996) is a relative humidity change of 20%. This is defined in three ways, (a) for objects that have a very high vulnerability this will definitely cause a crack each time. (b) Objects classified as having a high vulnerability have a possible chance of cracking each occurrence, and (c) those of medium vulnerability will be affected by gradual fatigue fracture. The projections for this part of the damage function are shown in figures C7a and b, again split for clarity.The results show that occurrence of these events are low, over the baseline and far future periods, with a slight increase observable. Oviedo is the exception, where the increase is approximately four times of the baseline value.

40% Humidity shock

The final category used by Michalski (1996) is a change of 40% relative humidity, from one day to the next. The projected occurrence for this at each location in the future is shown in figure C8. Only two locations, Oviedo and Leon feature, both minimally. From such little data it is difficult to conclude whether there is any real increase in the future. Shifts in relative humidity are likely to be freak occurrences, and such extremes are not dealt with well by the building simulation model. It tends to smooth out extreme values, as the method is based upon the monthly average.

Equilibrium Moisture Content

The final damage function to be assessed is that of the equilibrium moisture content (EMC) of wood. Incorrect values of EMC can be quite damaging, either too high or too low. Low EMC can cause cracking from drying out of wood, and high EMC could cause swelling of the wood, both especially important if an object is restricted from freely moving. Additionally high EMC could increase the risk of pest attack. Results for this damage function are shown in figure C9; again there is a split between the projected results for Almeria and the other locations. Almeria is projected to have an increasing EMC, and the other locations a decreasing EMC. The function to determine EMC is dependent upon the relative humidity, and comparison of the results here to the projected humidity confirms this dependence, as there is a good correlation between the two figures.

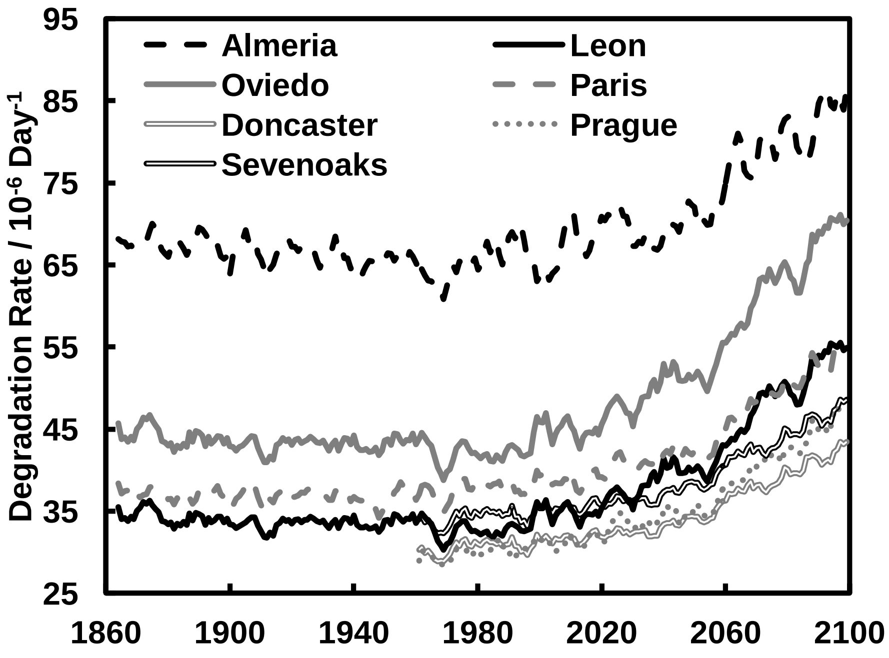


Figure C1: The Projected impact of climate change indoors on the relative degradation rate of paper, as estimated using the isoperm damage function. Projections for seven European locations, for the period 1860-2100. Results are plotted as a five year smoothed average.

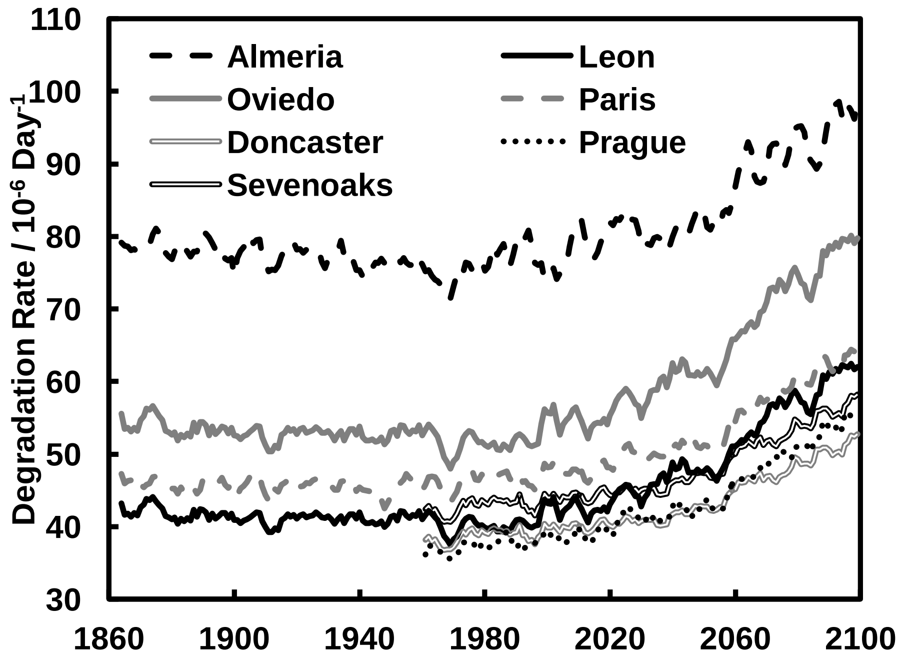


Figure C2: The projected relative degradation rate of paper using the TWPI damage function, from 1860 through to 2100 across the seven locations. The rate is shown as a 5 year smoothed average.

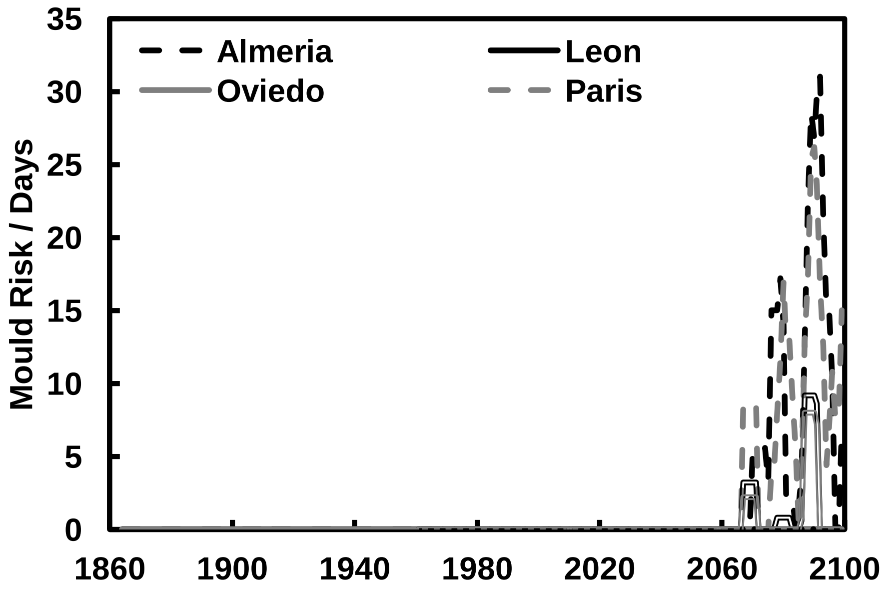
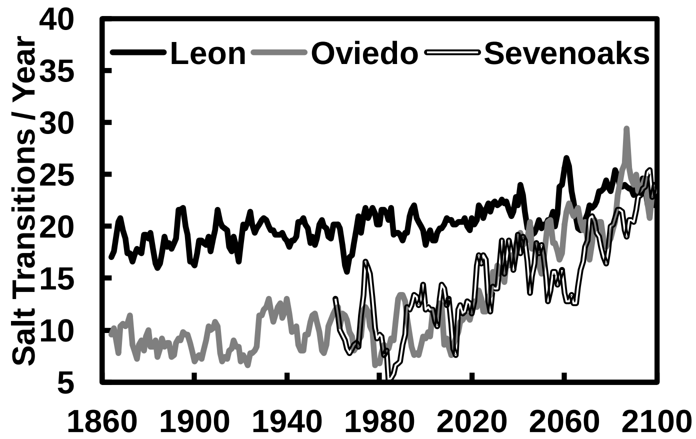


Figure C3: The number of projected days of mould growth from the Hukka and Viitanen model, across the seven European locations.



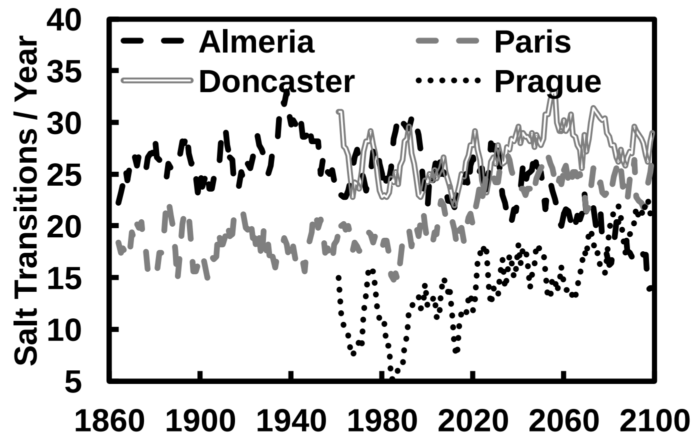


Figure C4 a and b: the impact of climate change on salt transitions at a critical humidity of 60%. Seven European locations are shown, with (a) having three of these and (b) the remaining four, these were split for clarity. Results are presented as fiver year smoothed averages from 1860 to 2100.

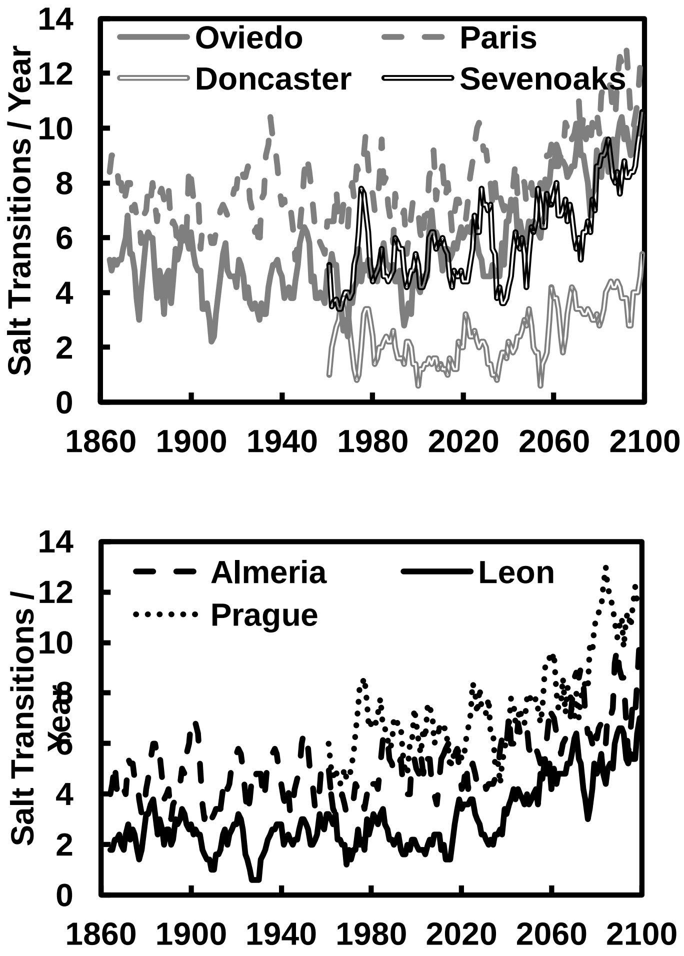


Figure C5 a and b: The projected impact of climate change on salt transitions at 85% for seven locations. (a) presents four of these and (b) three. Results are plotted as five year smoothed averages from 1860 to 2100.

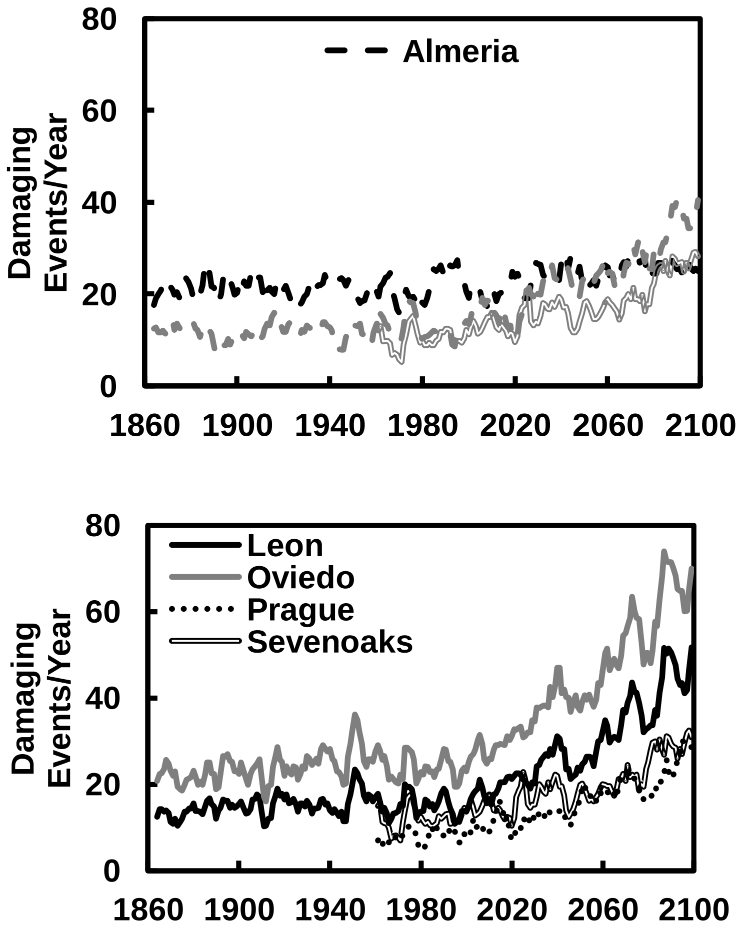


Figure C6 a and b: Projected yearly number of 10% humidity fluctuations, from one day to another, as described for the Michalski et al damage function. (a) shows three of the seven European locations and (b) the final four, they have been split for clarity. Results are plotted as five year smoothed averages, from 1860 to 2100.

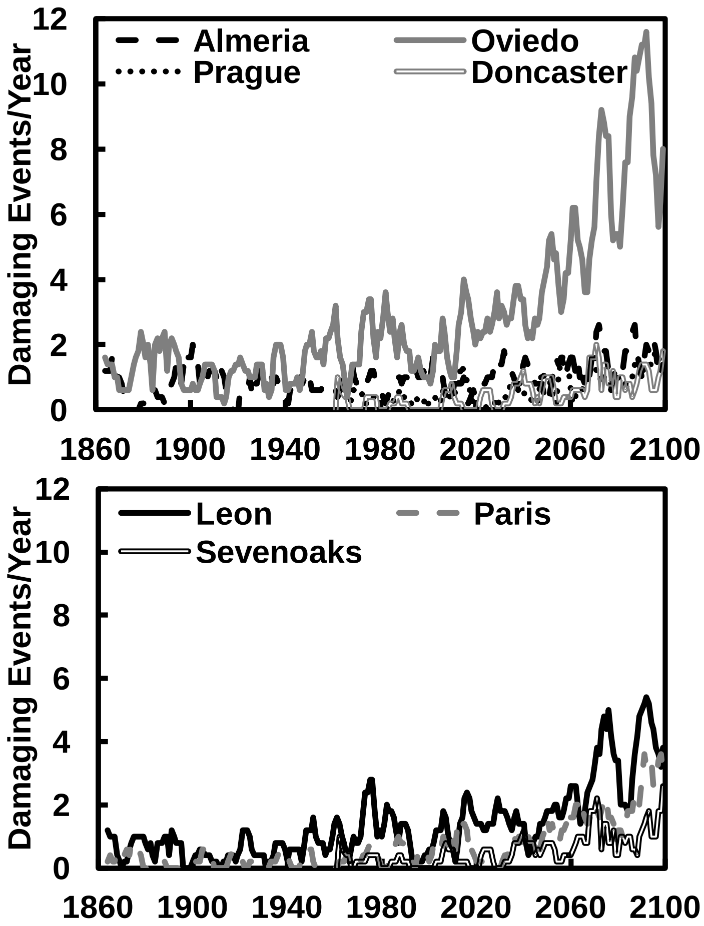


Figure C7 a and b: Projected impact of climate change on yearly number of day to day 20% humidity fluctuations, for the Michalski damage function. (a) plots four of seven locations and (b) the other three. Results are plotted as five year smoothed averages from 1860 to 2100.

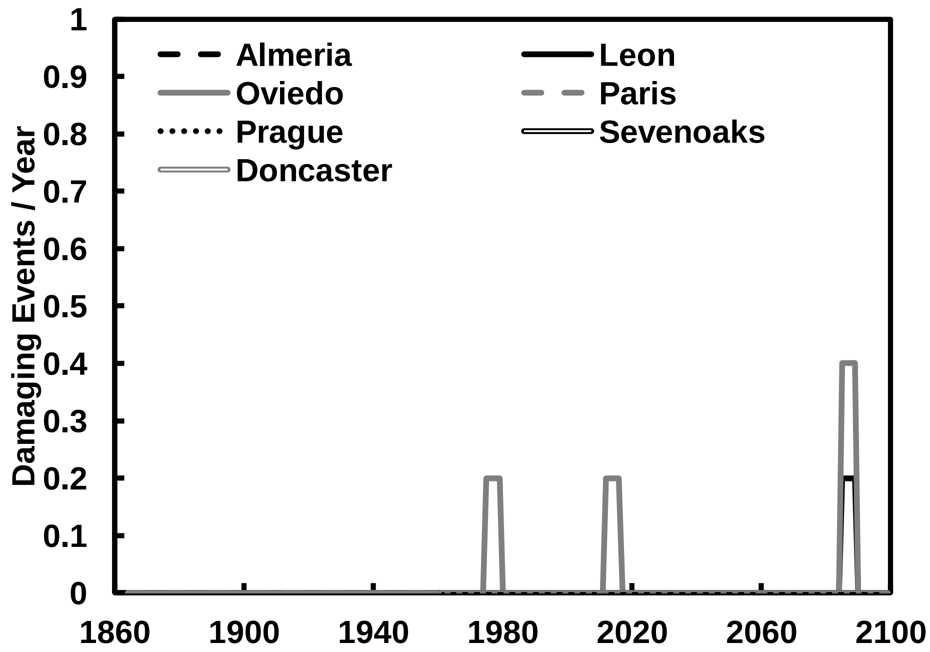


Figure C8: The projected impact of climate change on the yearly number of 40% day to day humidity fluctuations, as described by the Michalski et al damage function. Results for seven European locations are shown, from 1860 to 2100.

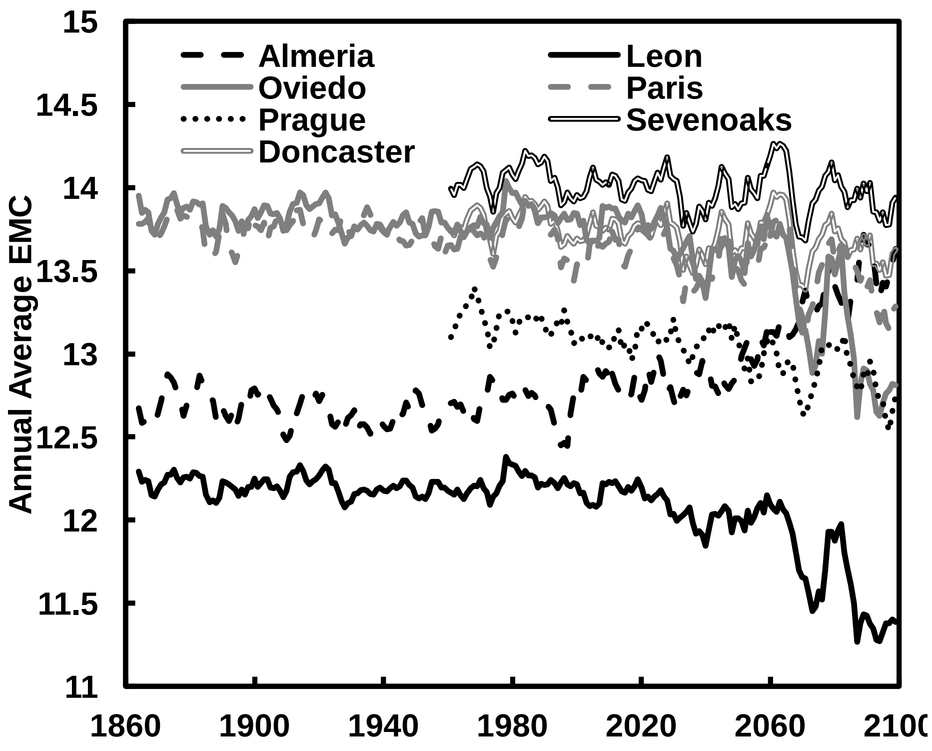


Figure C9: The projected impact of climate change on the annual average equilibrium moisture content of wood. Results for seven locations are shown, for the period 1860-2100. Results are plotted as five year smoothed averages

APPENDIX D
UKCP09 RESULTS

Knole

Daily average temperature >25°C

The projected impact of climate change on the number of days where the average temperature exceeds 25°C in the Cartoon and Leicester Gallery is shown in figure D1. For both rooms there were no days exceeding 25°C in the past, but going forward into the century these start to occur, increasing quite rapidly. The fact that these events did not occur in the past (or were very rare) means it is unlikely that the impact of this in the two rooms is unknown; there could be specific thresholds that will now be exceeded. The Median of the baseline period in the Cartoon Gallery is significantly different to the median of the near future period. It also follows that the median of the near future is significantly different to that of the mid-term future, and the mid-term future median is significantly different to that of the far future. The same is also true for the Cartoon Gallery.

The projection of days where the average temperature exceeds 25°C in the Cartoon Gallery is also shown in seasonal terms in figure D2. Following on from the previous measure (days over 20°C) it is July and August where the increase is expected in the future.

Isoperm

The projected change to paper degradation in the future, using the Isoperm damage function (section 4.2.2), in the Cartoon and Leicester Gallery is shown in figure D3. The results here are very similar to that of the Zou function, the overall increase is rate is approximately 1.5 times the baseline, and both rooms show similar results. The increase in rate is attributed also to the increase in temperature projected. The median of the baseline period for the Cartoon Gallery is significantly different to that of the near future, as is the near future median to the mid-term future median. The same is true of the mid-term to far future medians, and all three relationships are true for the Leicester Gallery also. The seasonal break down shown in figure D4 is also similar to that of the Zou function.

TWPI

The projected impact of climate change on the TWPI paper damage functions is shown in figure D5. As with the other paper damage functions the results are similar, although with just less than a 1.5 times increase in projected degradation rate from the baseline value. As may be expected from the figure, the baseline median is significantly different to that of the 2025 period, for both the Cartoon and Leicester Gallery. The same is true for the median of the 2025 period compared to the 2055 period median, and for the 2055 to 2085 median. As with the previous functions the seasonal results are also similar (figure D6), there is a greater increase in summer, but no overall shift in seasonality.

Hukka

The risk of mould growth over the coming century, as projected by this mould damage function (Hukka, section 4.4.2), is shown in figure D7. Again there is a stark difference between the two rooms, with the Cartoon Gallery having no risk of mould growth during the baseline period, and for some of the initial future periods, but having a number of days by the end of the century. The difference between the two rooms again is due to the relative humidity being either side of the critical value required; indicating how important it is to assess each room, particularly when there is a threshold value.

The median of the baseline period for the Leicester Gallery is significantly different to that of the near future period. The same is true of the median of the near future and mid-term future periods and the mid-term and far future periods, of the Leicester Gallery. The Cartoon Gallery is somewhat different, the medians of the near future and mid-term future are significantly different, as are the mid-term to far future medians. However, the median of the baseline period is not significantly different to the near future period, but the baseline is significantly different to the 2065 period.

The seasonal analysis of mould growth is shown in figure D8. This is similar to that previously of the Isaksson damage function, in the way that the risk of mould growth is delayed in comparison to when the ideal conditions occur.

Salt transitions – 60%

The impact of climate change on 60% salt transitions is shown in figure D9. In the Cartoon Gallery there is not a marked change in the number of transitions, and in the Leicester Gallery the transitions are projected to increase, but only slightly, and reach a plateau by the 2055 period. Whether the slight change has a significant impact on damage is unknown. It will depend upon the damage caused by an individual transition. With this being a hypothetical damage function it is not possible to define the damage caused.

For the Cartoon Gallery the baseline median is not significantly different to that of the near future, but is significantly different to that of the mid-term future period. For the Leicester Gallery the baseline period median is significantly different to that of the near future, as is the near future to mid-term future. However the mid-term future and far future medians are not significantly different.

The seasonal analysis of the salt transitions is shown in figure D10. The results show that the change in relative humidity, with more humid winters and less humid summers has an impact on the transitions. Each change has the opposite effect, the less humid summers cause an increase in transitions, and the more humid winters cause a decrease in transitions.

10% humidity shock

The impact that climate change is projected to have on dimensional change to wood, caused by 10% humidity shifts is shown in figure D11. There is a decrease projected in both rooms, the seasonal analysis (figure D12) of the Cartoon Gallery indicates a similar pattern to the 5% function, although the reduction in events is more evenly spread across the year, possibly with the exception of the winter months.

The baseline period median is significantly different to that of the near future period, for both rooms. The same is true of the near future median and mid-term future median, as is the mid-term future and far future median. However it is difficult again to assess the significance of such a change on the damage that will propagate, and how this in turn affects the preventive measures put in place to prevent such damage. This topic is covered in greater depth in chapter 8.

20% humidity shock

The impact that climate change is projected to have on this dimensional change damage function is shown in figure D13. A reduction in the number of events is projected for both the Cartoon and Leicester Gallery. This reduction appears to be driven by the spring and autumn months, as shown in the seasonal analysis (figure D14). For both rooms the median of the baseline period is significantly different to that of the near future. The same is true of both the near future to mid-term future, and the mid-term future to far future. It is also likely that, given the significance of such a large relative humidity change, the reduction seen here will be a significant positive improvement to the environment, reducing the damage to collections containing wood susceptible to dimensional change.

Cotton Wood total

The impact of climate change on the total damage to cotton wood, from both adsorption and desorption events is shown in figure D15. As expected the number of damaging events decreases across the century. The median of the baseline period, for both rooms, is significantly different to the median of the near future period. The median of the near future period is also significantly different to that of the mid-term future, as is the mid-term to far future medians. The combination of the two mechanisms of damage, assessed on a month by month basis is shown in figure D16.

White Oak adsorption

The impact of climate change on dimensional change adsorption events to objects constructed of white oak is shown in figure D17. The principle here is similar to that of the previous cotton wood damage functions, therefore the reduction in damaging events projected here, in both rooms, is due to the reduction of summer humidity. This is shown in the seasonal analysis in figure D18. The median of the baseline period is significantly different to that of the near future period, in both rooms. The same is true of the near future median to mid-term future median, and also to that of the mid-term to far future medians. The projected reduction in damaging events is quite small, in both rooms, and thus is unlikely to have a significant impact on the level of damage observed, and the conservation measures in place to prevent such damage.

White Oak desorption

The impact of climate change on damaging desorption events to white oak is shown in figure D19. It is expected that the number of damaging events will decrease in both the rooms assessed here. This reduction is driven by the summer months (figure D20), when there is projected to be less humid months in the future. Previously the Leicester Gallery has been projected to have a greater number of damaging events than the Cartoon Gallery, here however the difference between the two rooms is negligible, particularly across the future periods. For the Cartoon Gallery the median of the baseline period is significantly different to that of the near future period, the same applies to the median of the near future and the mid-term future, the mid-term and future medians are also significantly different. The same is true for these three comparisons in the Leicester Gallery.

White Oak total

The combination of the impact of climate change to both the adsorption and desorption events on white oak is shown in figure D21, and seasonally in figure D22. As both of these are projected to reduce individually the same is true here, for both rooms, and the seasonal analysis presents similar results. In total for each room there are a significant number of damaging events, however, the somewhat substantial reduction that is projected is unlikely to have a significant impact of the management of this damage. The impact on damage itself is more difficult to determine, and is likely to depend on the individual circumstances. The projected median value of the baseline period is significantly different to that of the near future period, for both rooms. The same is true for the near future to mid-term future median, and also the mid-term future to far future median.

Equilibrium Moisture Content

The final damage function that is assessed at Knole is that of the equilibrium moisture content of wood. The impact that climate change is projected to have on this function is shown in figure D23.

This function is heavily dependent on the relative humidity, thus it is no surprise that the annual average EMC shows no overall change across the coming century. However, looking at the seasonal data (figure D24), there is a change in the EMC, with a reduction in summer and an increase in winter months, the same as projected for relative humidity.

The median for the baseline period, of both rooms, is significantly different to the median of the near future period. For the Leicester Gallery the near future median is significantly different to that of the mid-term future. However the Cartoon Gallery near future median is not significantly different to that of the mid-term future. In both rooms the mid-term future median is significantly different to that of the far future.

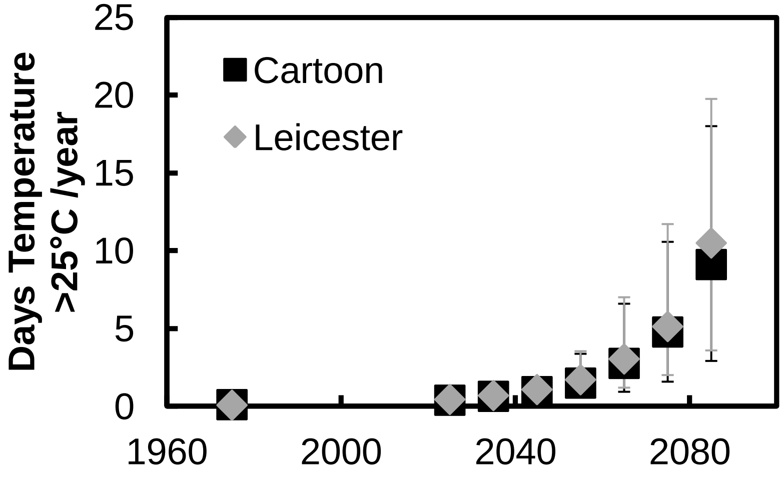


Figure D1: Impact of climate change on days where temperature >25°C.

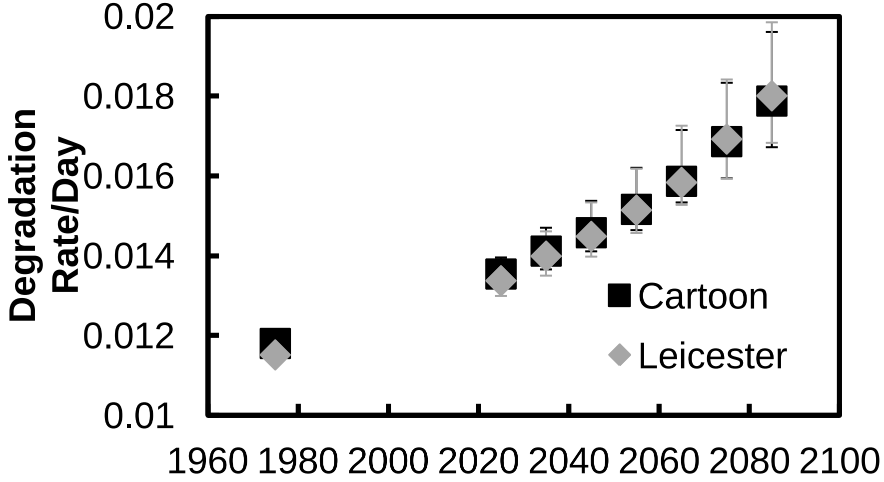


Figure D3: Impact of climate change on the Isoperm damage function.

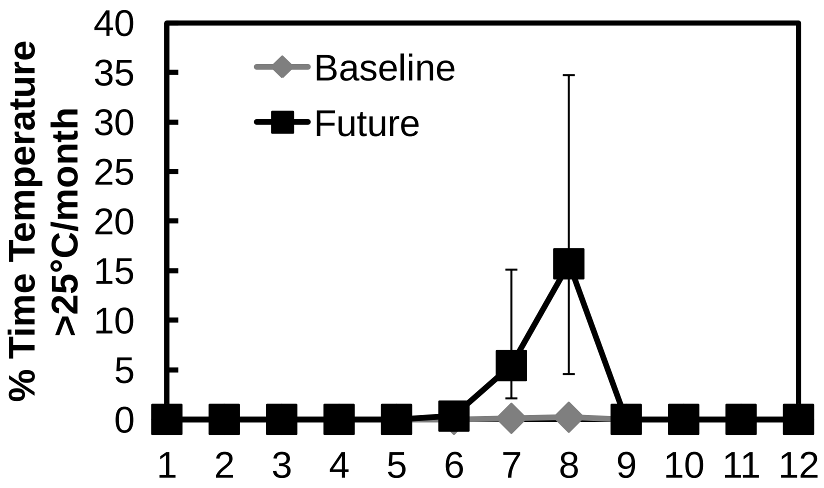


Figure D2: Seasonal impact of climate change on days where T >25°C.

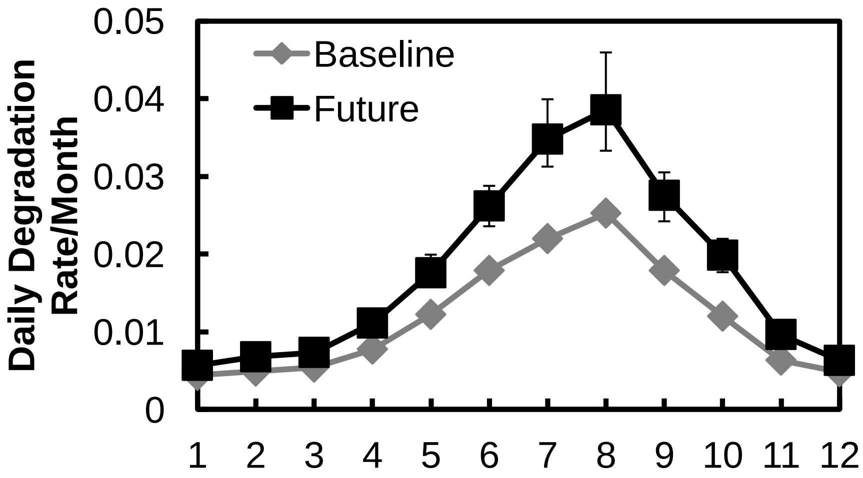


Figure D4: Seasonal impact on the Isoperm damage function.

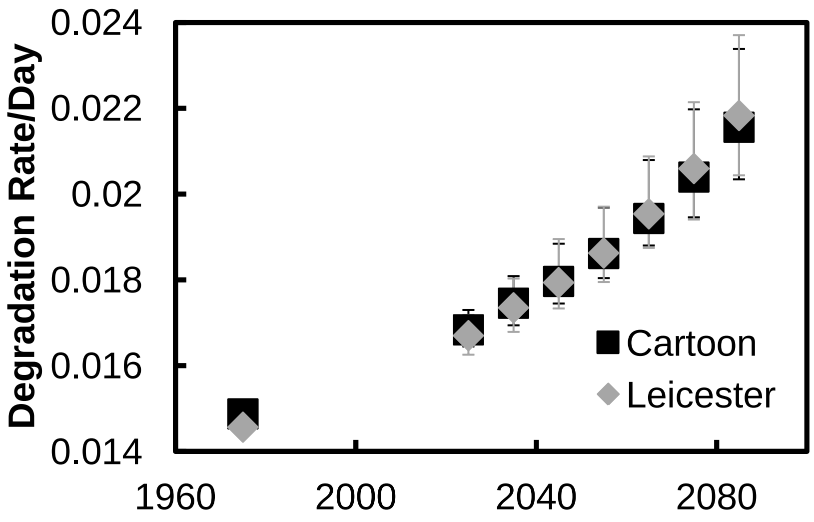


Figure D5: Impact of climate change on the TWPI damage function.

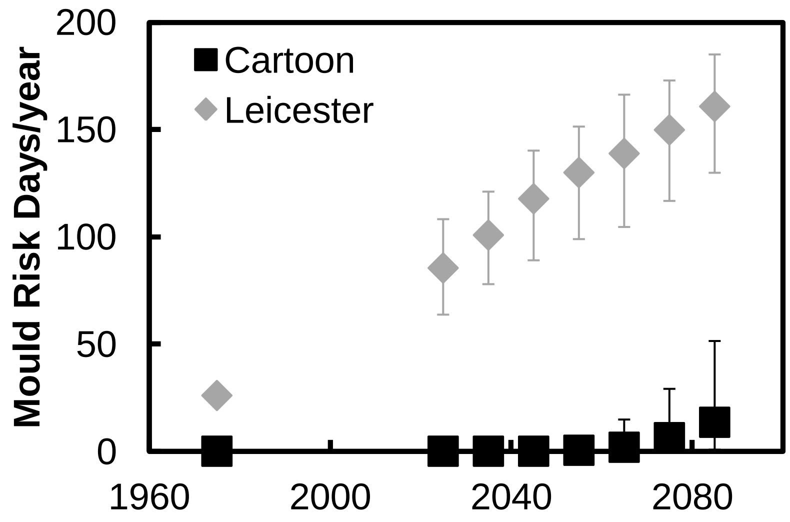


Figure D7: Impact of climate change on the Hukka damage function.

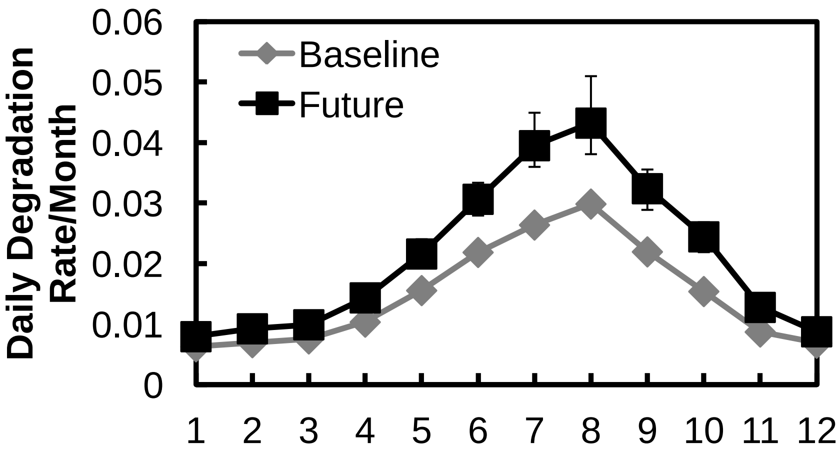


Figure D6: Seasonal impact on the TWPI damage function.

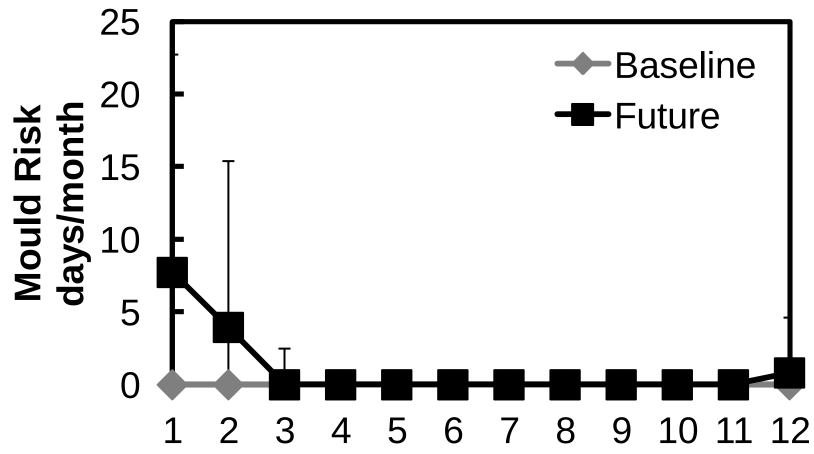


Figure D8: Seasonal impact on the Hukka damage function.

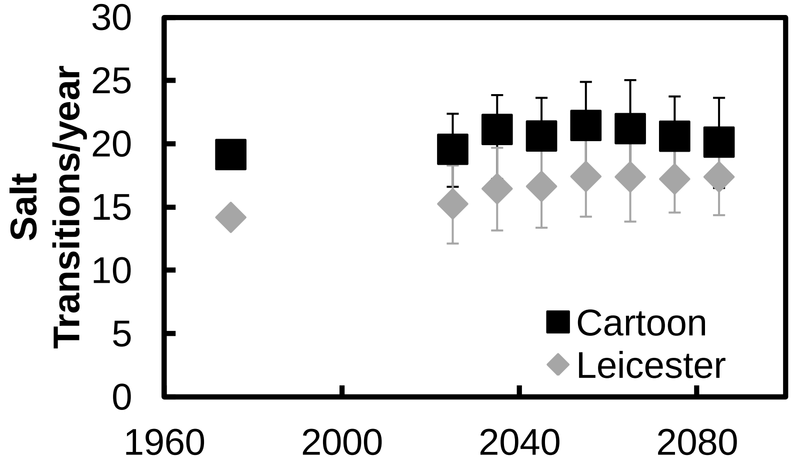


Figure D9: Impact of climate change on 60% salt transitions.

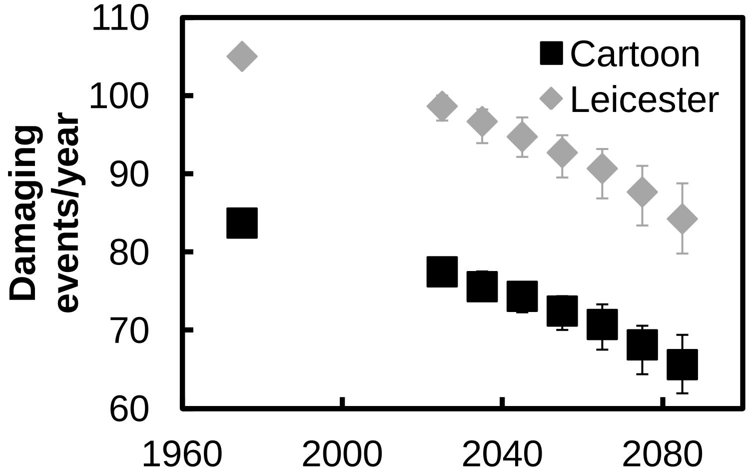


Figure D11: Impact of climate change on 10% humidity shocks.

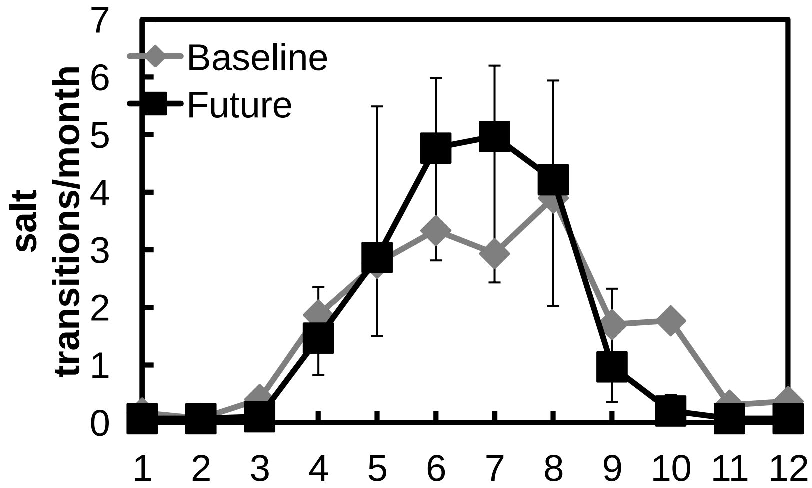


Figure D10: Seasonal impact of climate change on 60% salt transitions.

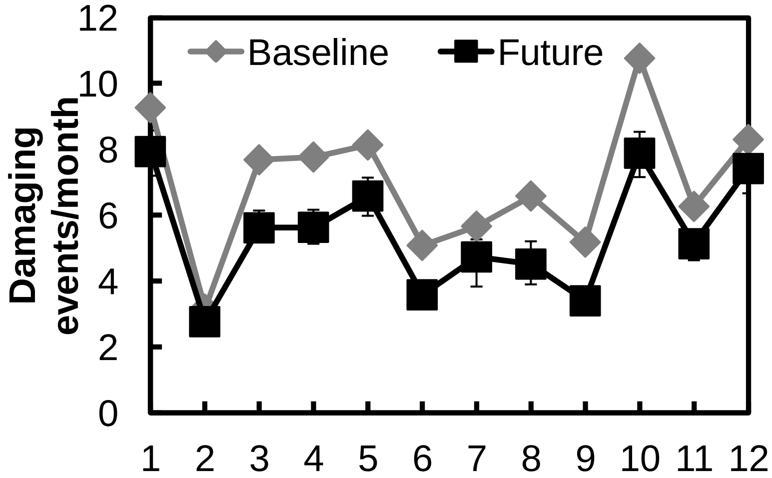


Figure D12: Seasonal impact of climate change on 10% humidity shocks.

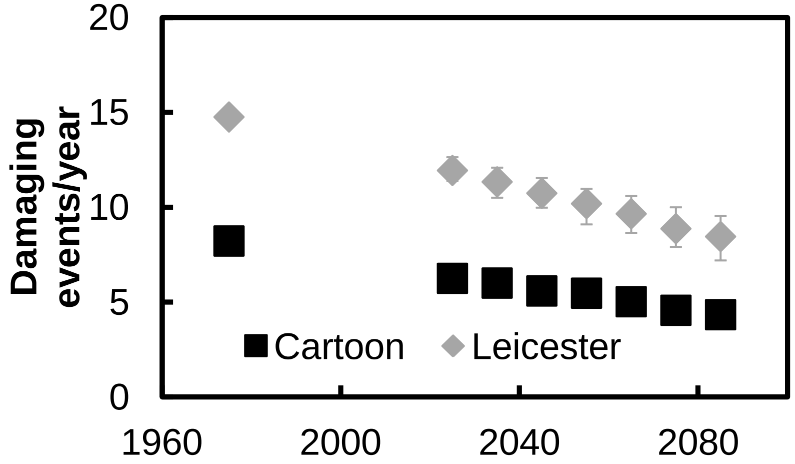


Figure D13: Impact of climate change on 20% humidity shocks.

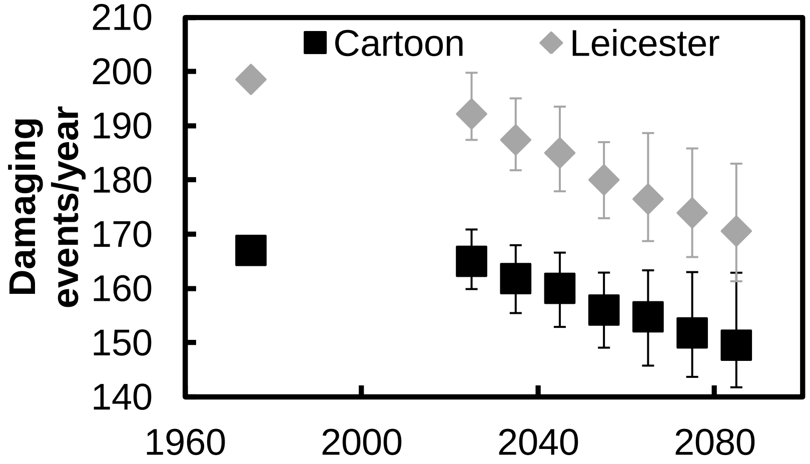


Figure D15: Impact of climate change on Cotton Wood damaging events.

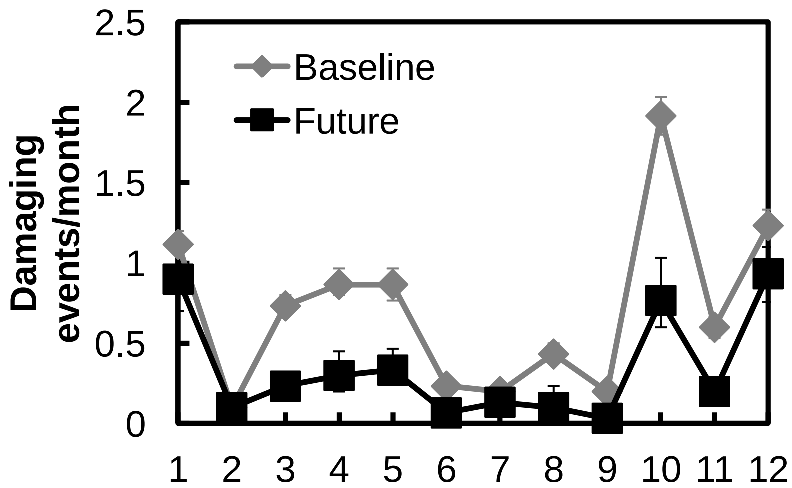


Figure D14: Seasonal impact of climate change on 20% humidity shocks.

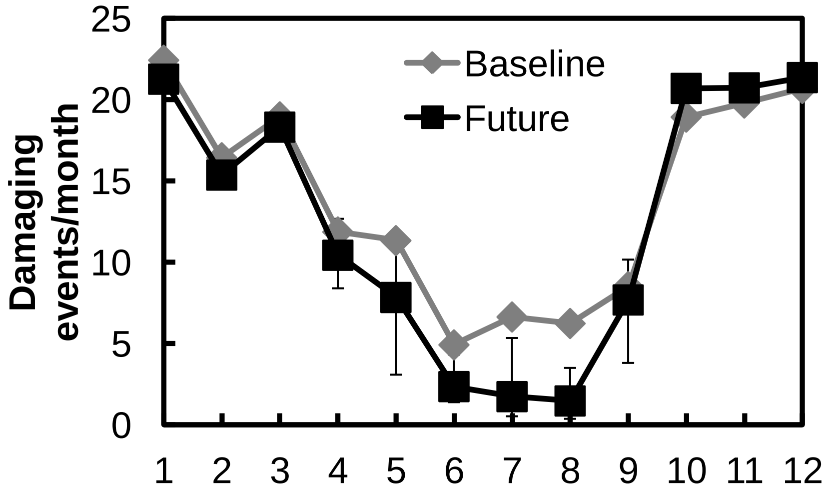


Figure D16: Seasonal impact on Cotton Wood damaging events.

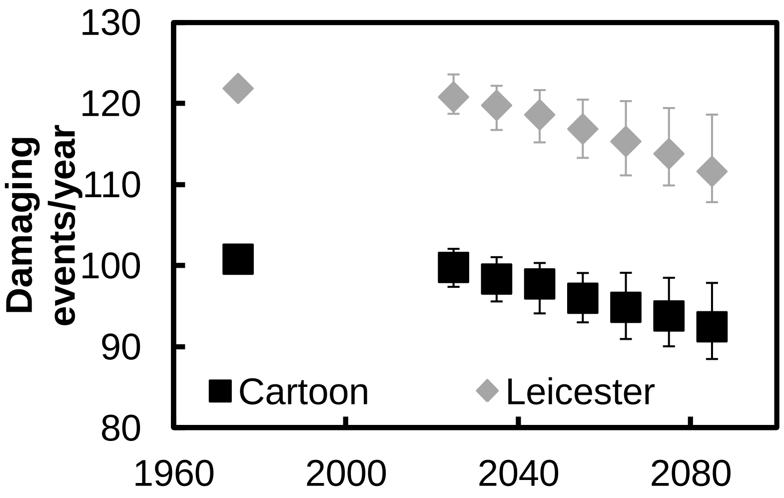


Figure D17: Impact of climate change on White Oak adsorption events.

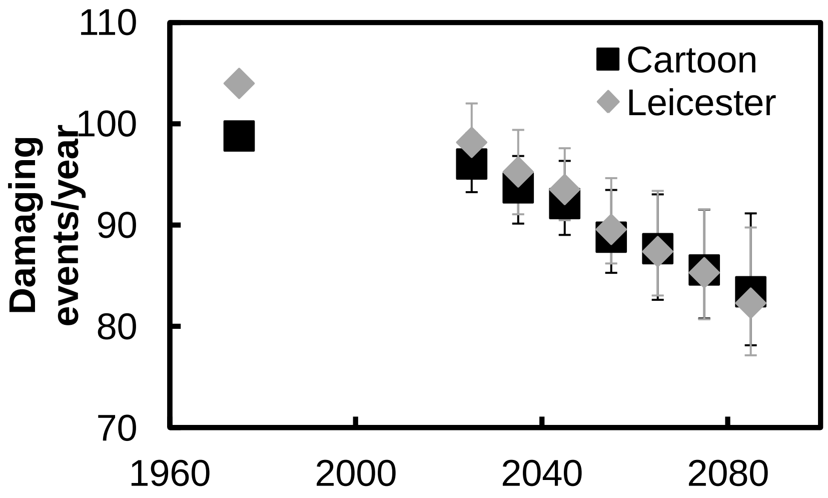


Figure D19: Impact of climate change on White Oak desorption events.

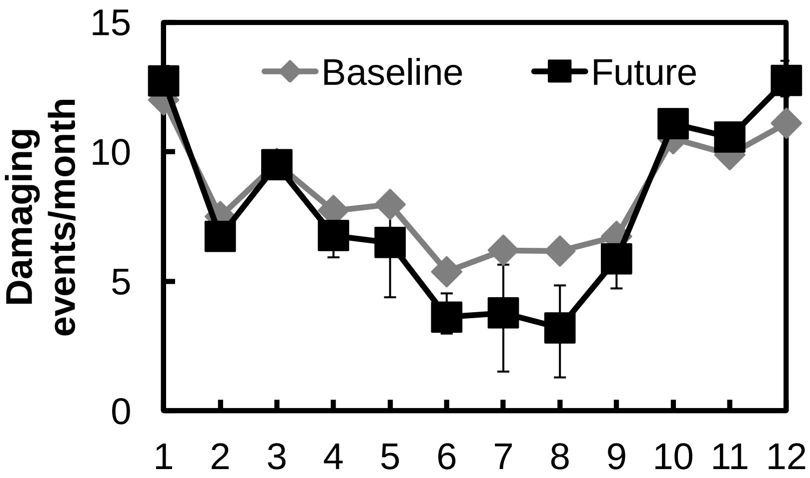


Figure D18: Seasonal impact on White Oak adsorption events.

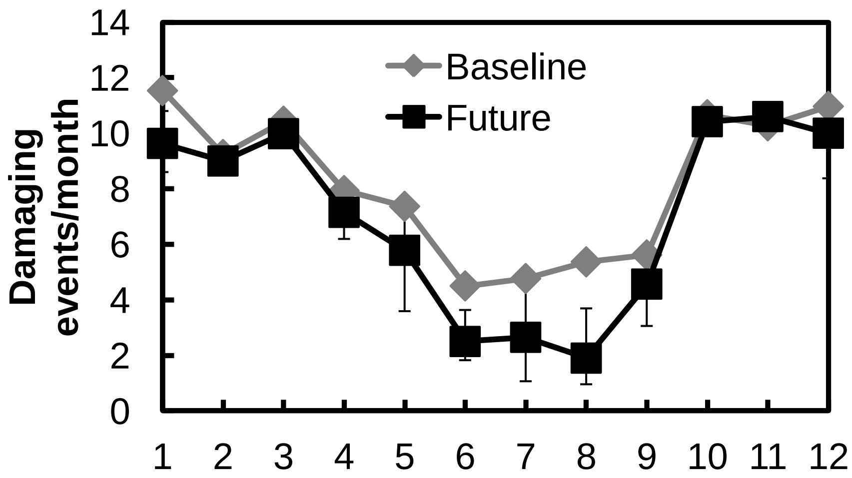


Figure D20: Seasonal impact on White Oak desorption events.

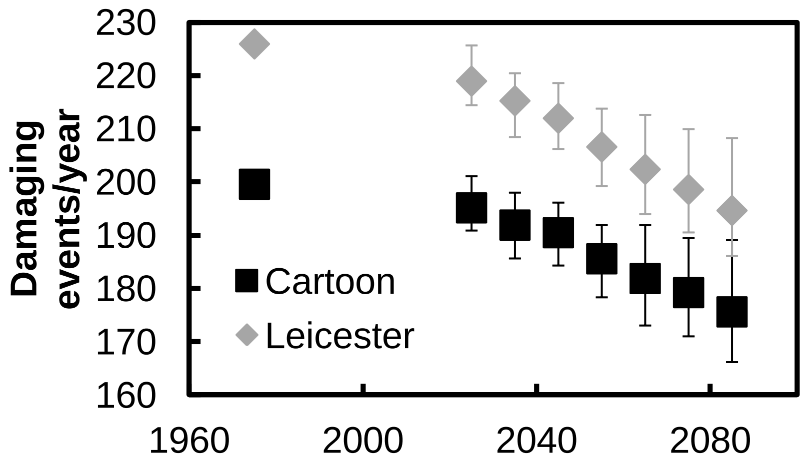


Figure D21: Impact of climate change on White Oak damaging events.

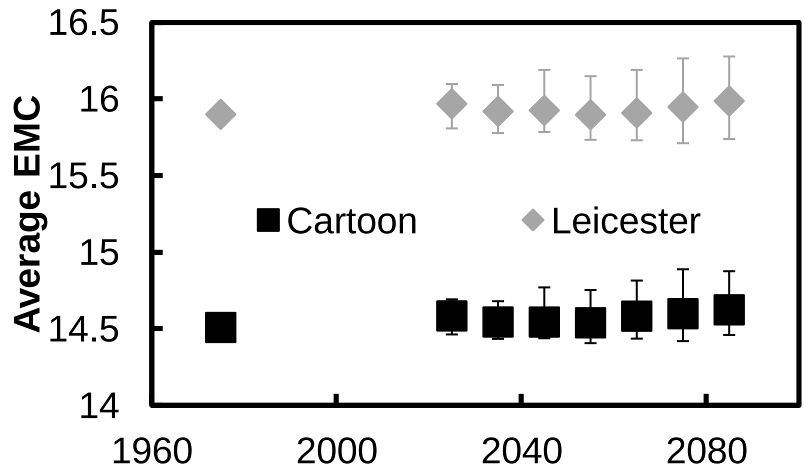


Figure D23: Impact of climate change on equilibrium moisture content.

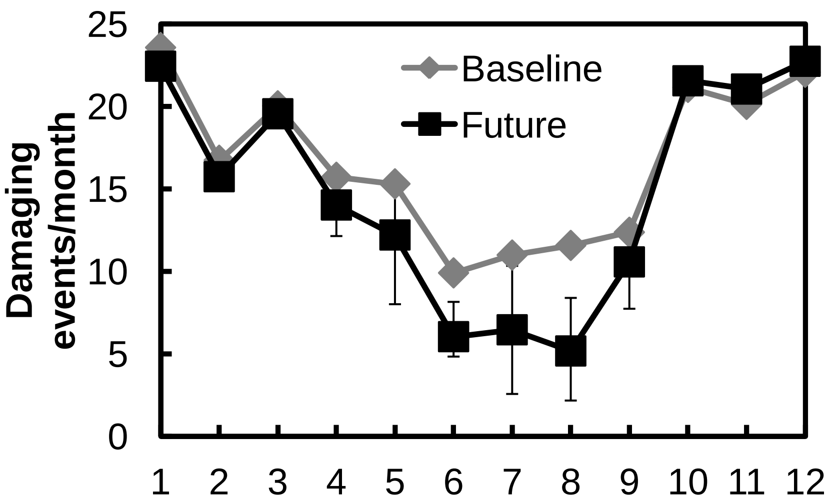


Figure D22: Seasonal impact on White Oak damaging events.

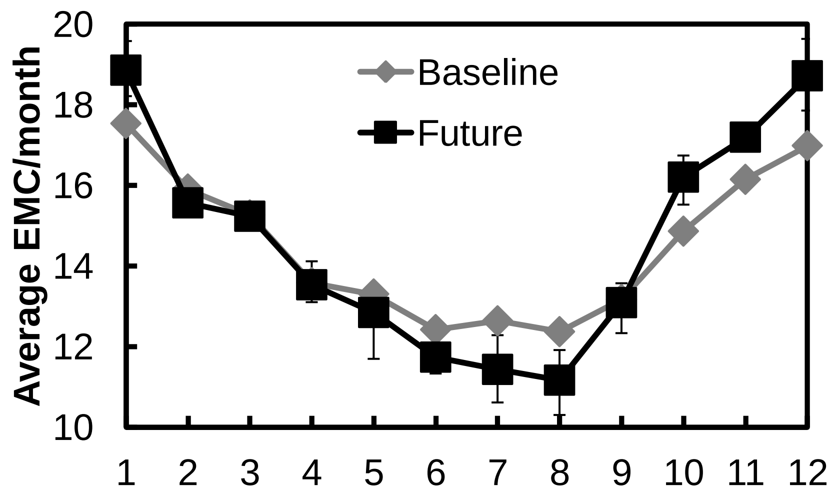


Figure D24: Seasonal Impact on equilibrium moisture content.

Brodsworth

Daily average temperature >20°C

The projected impact of climate change on the number of days where the average temperature exceeds 20°C is shown in figure D25. This is projected to increase quite dramatically, with almost twice as many days in the far future. The median of the baseline period is significantly different to the median of the near future period. The same is true of the near future and mid-term future medians, and also of the mid-term and far future medians. In terms of seasonality (figure D26), as expected it will be in the summer months where an increase in the number of days over 20°C is seen. July and August will almost always be in excess of 20°C in the far future, with the two months either side of these having a dramatic increase in the number of days over 20°C.

Zou

The impact that climate change is projected to have on damage to paper as projected by the Zou damage function in the Library at Brodsworth Hall is shown in figure D27. The damage function is solely dependent upon temperature, thus the projected increase in the rate of chemical degradation to paper can be attributed to the projected increase in temperature. The seasonal analysis of the change in degradation rate is shown in figure D28. This shows similarity with the corresponding temperature seasonality data, with a greater increase in the rate during the summer months, and all months projected to have an increase in the degradation rate. The median of the baseline period is significantly different to the median of the near future period. The same is true for the median of the near future and mid-term future median, and also of the mid-term and far future medians. It is expected that the projected increase will be significant within the Library, there is a great quantity of paper in the Library, and an increase in the rate at which it will degrade will shorten the useable lifetime of the books. Whether the increased rate will be sufficient to raise concerns is unknown, it is unlikely to significantly affect the preventive conservation measures in place to prevent this damage.

TWPI

The impact that climate change is projected to have on the chemical degradation of paper, as described by the TWPI damage function is shown in figure D29, and the seasonal analysis of the function is shown in figure D30. The baseline period median is significantly different than the median of the near future median. This is also true of the near future median and the mid-term future median, and also the mid-term and far future median.

Pretzel

The impact that climate change is projected to have on this paper damage function is shown in figure D31. As described previously this function places a greater emphasis on the relative humidity than the other paper damage functions. This explains why there are different results shown here. The rate is projected to increase, but reaches a plateau by the end of the century. The median of the baseline period is not significantly different than the median of the near future period, however it is significantly different than the median of the mid-term future period. The mid-term future period median is not significantly different to the far future median.

The seasonal analysis of this damage function is shown in figure D32. While the interquartile ranges overlap somewhat, it is projected that most months contribute to the increase in the rate projected. April is an exception to this rule. It is not apparent whether it is the increase in temperature of the increase in relative humidity that is the dominant factor in the projected increase in rate.

Silk isoperm

The impact that climate change is projected to have on chemical damage to silk in the Library at Brodsworth Hall is shown in figure D33. The damage function is dependent on temperature alone, therefore this is the reason that the rate is projected to increase in the future. The seasonal analysis of this function is shown in figure D34; this is similar to that of the previous damage functions that are dependent on temperature. The median of the baseline period is significantly different to that of the near future period. The same is true of the near future median and the mid-term future median, and also the mid-term future and far future medians.

Salt transitions – 75.3%

The impact that climate change is projected to have on the salt transitions of Halite is shown in figure D35. The relative humidity on average in the Library for the baseline period is quite low in comparison to the critical value here, thus transitions are a rare occurrence. However, the projected rise in relative humidity raises the risk of one of these transitions occurring. If there was an object in this room that was highly susceptible to damage because it contains halite then the increase of risk from zero to approximately one transition every three years would prove significant, and depending upon the significance of the object, possibly require preventive conservation measures. The median of the baseline period is significantly different to the median of the near future period. The same is true of the near future median and the mid-term future median, and also the mid-term and far future median. The seasonal analysis (figure D36) indicates that it is the month of October that poses the main risk of transitions.

5% humidity shock

The impact that climate change is projected to have on damage caused by dimensional change, as described by this function is shown in figure D37. It is projected that there will be fewer 5% shifts in relative humidity from day to day in the future. Given that there is such a high number of damaging events it is unlikely that such a reduction would prove significant in terms of the damage caused, or the conservation measures implemented. Statistically however the baseline median is significantly different to that of the near future period. The same is also true of the near future median and the mid-term future median, and also of the mid-term and far future medians. The seasonal analysis (figure D38) indicates that there is a reduction in events in every month, with the spring and summer months contributing greatest to this reduction.

10% humidity shock

The impact that climate change is projected to have on dimensional change to wood, as described by this damage function is shown in figure D39. A decrease in the number of damaging events is projected in the future, with approximately a 25% reduction in the number of events. The seasonal analysis (figure D40) indicates that there is a reduction projected in every month. The median of the baseline period is significantly different to the median of the near future period. The same is true of the near future median and mid-term future median, and also the mid-term and far future medians.

30% humidity shock

The impact that climate change is projected to have on dimensional change to wood, as described by this damage function is shown in figure D41. Here the number of events is less than one per year, so can be interpreted as the probability of one event occurring in a year. There is a reduction in this risk in the future, from one event every five years to one less than every 20 years. This change is unlikely to be significant, a risk such as that at the baseline period is very low, such that measures to prevent this damage are unlikely, therefore no change would occur if this risk decreases as projected. Statistically the median of the baseline period is significantly different to that of the near future period. The same is true of the near future and mid-term future medians. However the mid-term future and far future medians are not significantly different. The greatest portion of the risk during the baseline period is from the month of December (figure D42), this reduces in the future.

Cotton Wood adsorption

The impact that climate change is projected to have on the number of damaging events to cotton wood caused by adsorption of moisture is shown in figure D43. In contrast to the previous dimensional change damage functions there is an increase projected here. The increase is small in terms of magnitude, but if each event causes damage then this will accelerate this, where two events per year may have been tolerable the 3.5 in the future may not be, thus requiring additional management of the situation, making the change significant. Statistically the median of the baseline period is significantly different to that of the near future period. However the near future median is not significantly different to that of the mid-term future median. The mid-term future median however is significantly different to the far future median. The seasonal analysis of this function in shown in figure D44, indicating that it is the months of August, September and October where the number of damaging events is expected to rise in future. The reason for this is likely to be because the relative humidity is increasing, moving into the region which does not allow as much humidity fluctuation before a damaging event occurs.

Cotton Wood desorption

The impact of climate change on the number of damaging events to cotton wood, as caused by dimensional change, driven by the desorption of moisture, is shown in figure D45. The number of desorption events is projected to decrease in the future. While there is an initial decrease in events this plateaus after the 2035 period. The seasonal analysis of this function (figure D46), indicates that there is a reduction in events for all months but August, September and October. Statistically the median of the baseline period is significantly different to the median of the near future period. The same is also true of the near future to mid-term future median, and also of the mid-term to far future medians.

Cotton Wood total

The result of the impact of climate change on both the adsorption and desorption damaging events to cotton wood is shown in figure D47. Overall the result is an increase in the number of damaging events, driven by the adsorption events. The majority of these are projected to come from the month of October (figure D48). The median of the baseline period is not significantly different to that of the near future period; it is significantly different to the far future period however. The result is unlikely to be significant in terms of the preventive conservation measures in place.

White Oak desorption

The impact that climate change is projected to have on dimensional change to white oak, as caused by desorption events is shown in figure D49. An increase in the number of damaging events is projected, with an additional two by the end of the century, compared to the baseline. This is unlikely to prove significant in terms of damage and preventive conservation measures. Statistically however the median of the baseline is significantly different to that of the near future period. The near future period is not significantly different to the mid-term future period. This is due to the increase from the baseline to near future, which then decreases to the 2035 period, but then increases again, thus the near and mid-term future show similar results. The reason for this drop is unknown, it does not correlate with the projected relative humidity, and it is possible that it is related to the damage function itself. The seasonal analysis of this function is shown in figure D50, indicating again that it is the months of August, September and October that drive the increase in damaging events; these are the months where humidity is at its highest in the Library.

White Oak total

The impact of climate change on the projected total of adsorption and desorption damaging events to white oak wood is shown in figure D51. As expected with both individually projected to increase the total also does. In total there is an increase of almost 50% from the baseline to far future period, this is likely to have a significant impact on damage, but unlikely to significantly impact the conservation strategies adopted. The seasonal analysis is shown in figure D52, following the same trend as the individual analyses.

White Oak failure

The projected impact of climate change on this damage function is shown in figure D53. It is projected that there is a reduction in the number of failure events in future in the Library. The probability of an event occurring was rare, so it is unlikely to be a significant change, in terms of damage or preventive conservation measures. Statistically the median of the baseline period is significantly different to that of the near future period. The same is also true of the near future to mid-term future medians, however the mid-term to far future medians are not significantly different. The month to month analysis of this damage function is shown in figure D54, where previously the winter months, particularly December, contributed to the risk. However, in the future the risk is reduced, with only December contributing, and less so than previously.

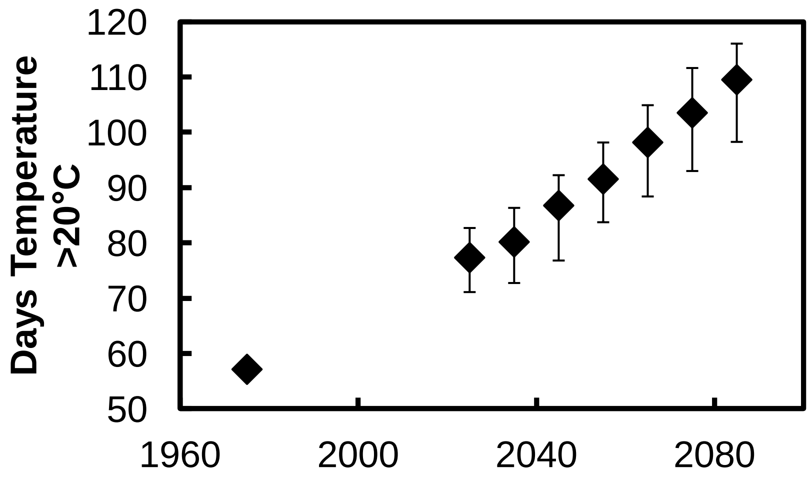


Figure D25: Impact of climate change on days temperature >20°C.

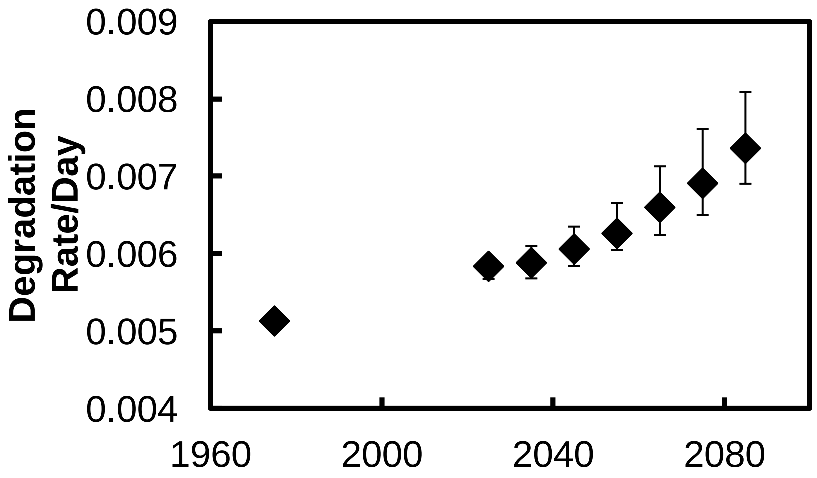


Figure D27: Impact of climate change on the Zou damage function.

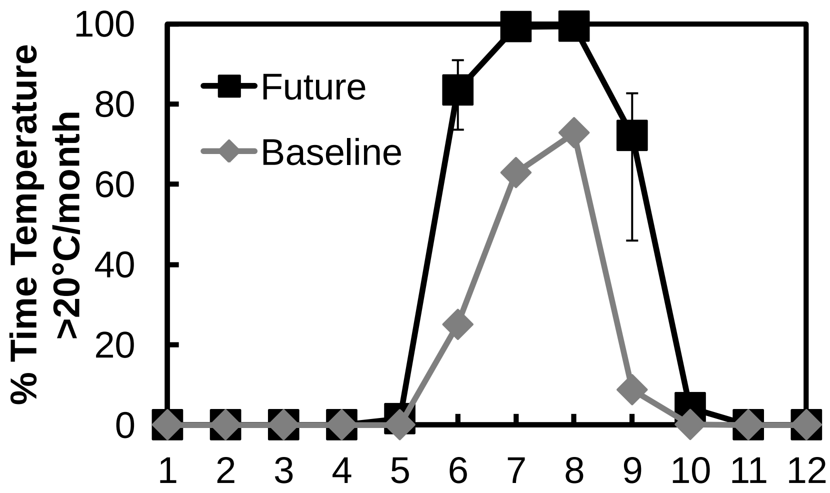


Figure D26: Seasonal impact on days where temperature >20°C.

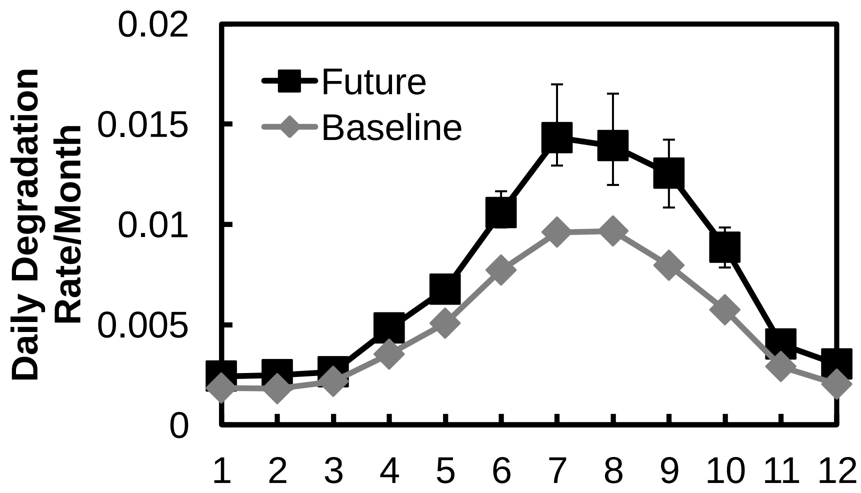


Figure D28: Seasonal impact of climate change on the Zou function.

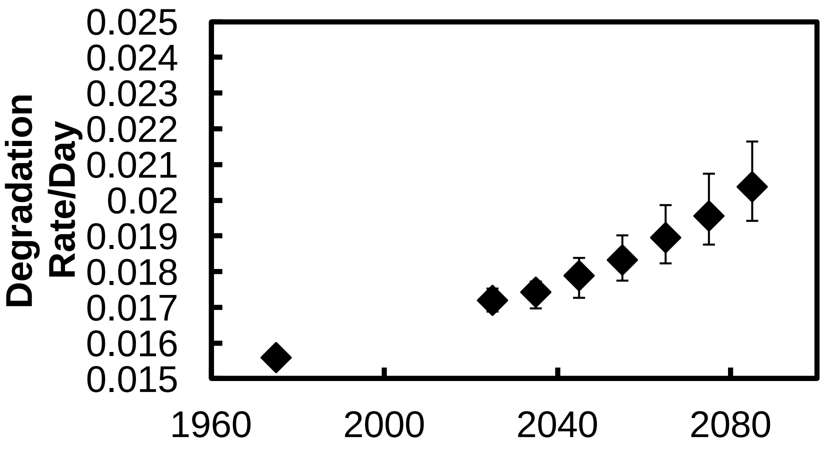


Figure D29: Impact of climate change on the TWPI damage function.

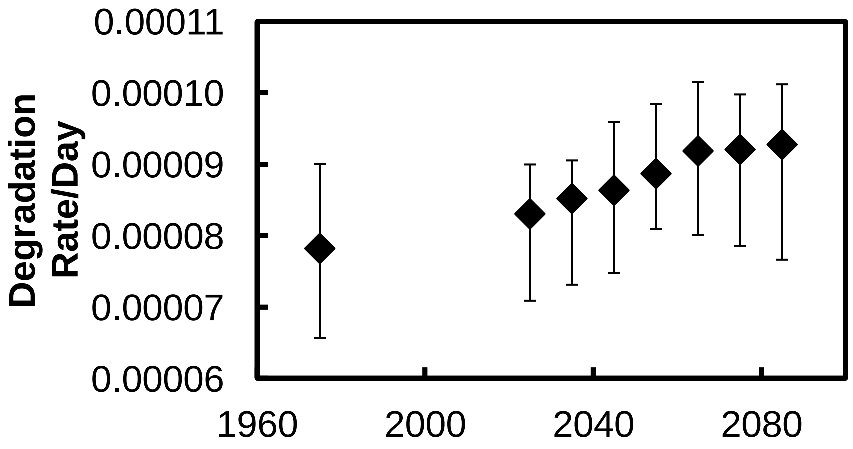


Figure D31: Impact of climate change on the Pretzel damage function.

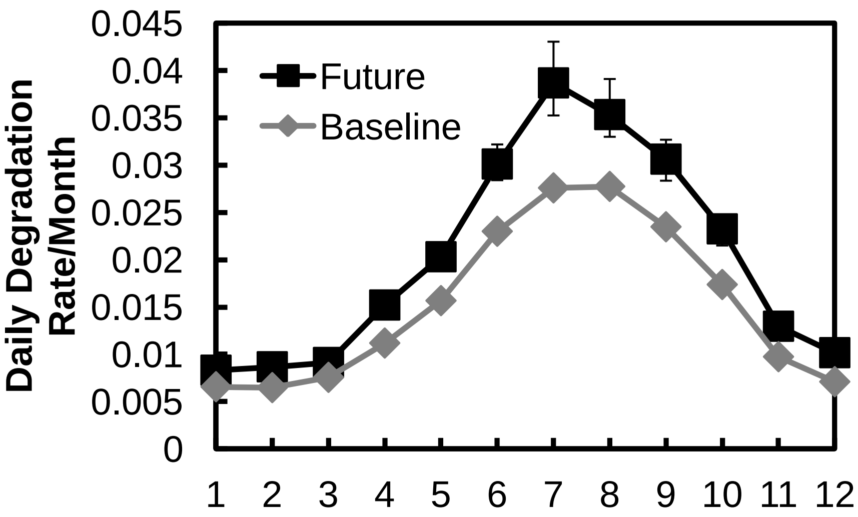


Figure D30: Seasonal impact of climate change on the TWPI function.

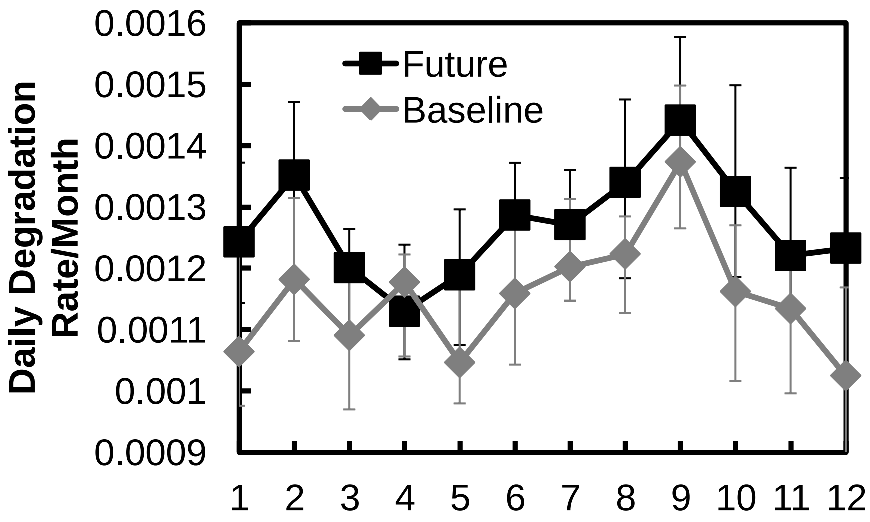


Figure D32: Seasonal impact of climate change on the Pretzel function.

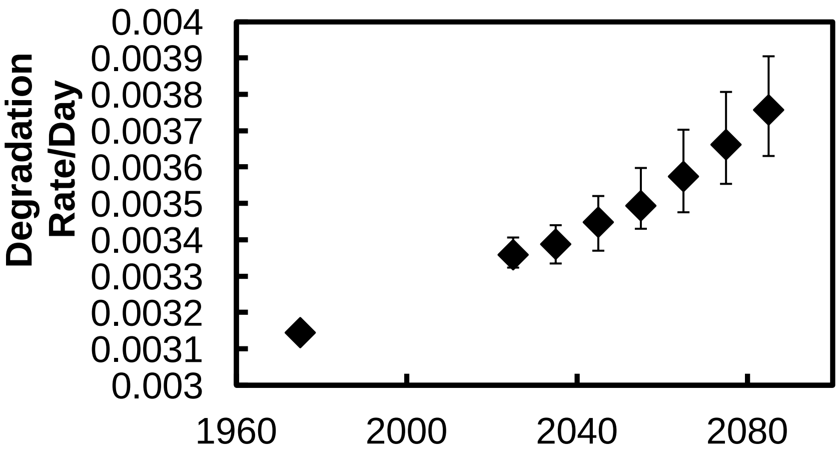


Figure D33: Impact of climate change on the silk damage function.

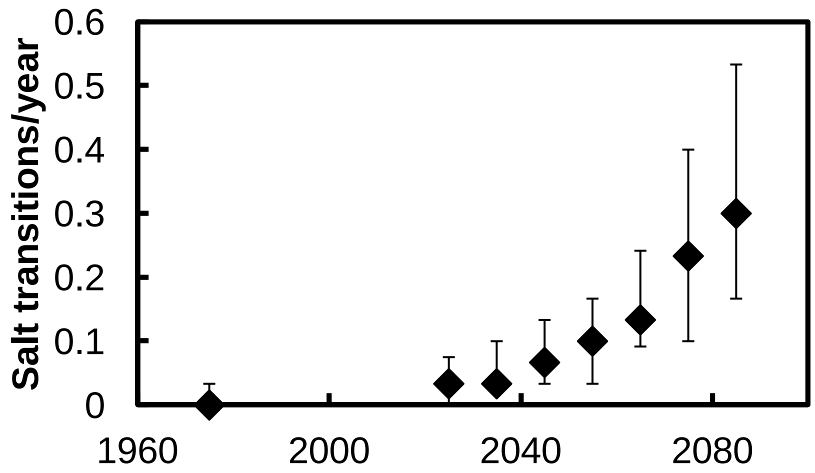


Figure D35: Impact of climate change on 75.3% salt transitions.

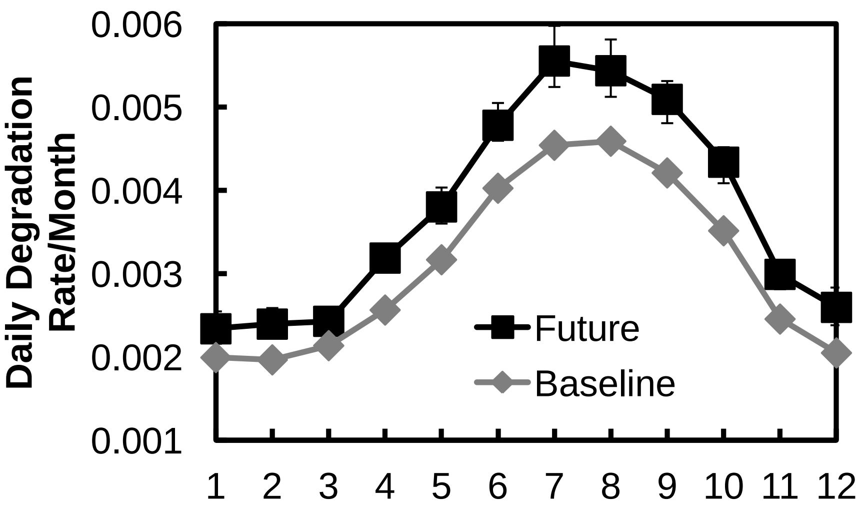


Figure D34: Seasonal impact on the silk damage function.

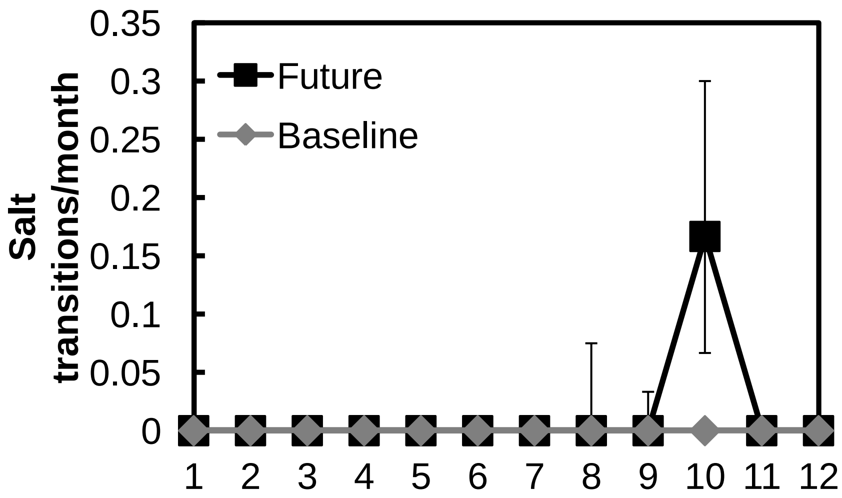


Figure D36: Seasonal impact of climate change on 75.3% salt transitions.

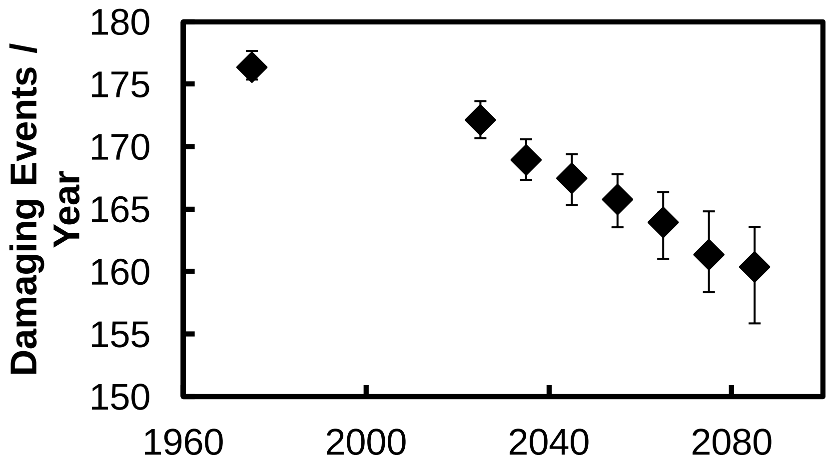


Figure D37: Impact of climate change on 5% humidity shocks.

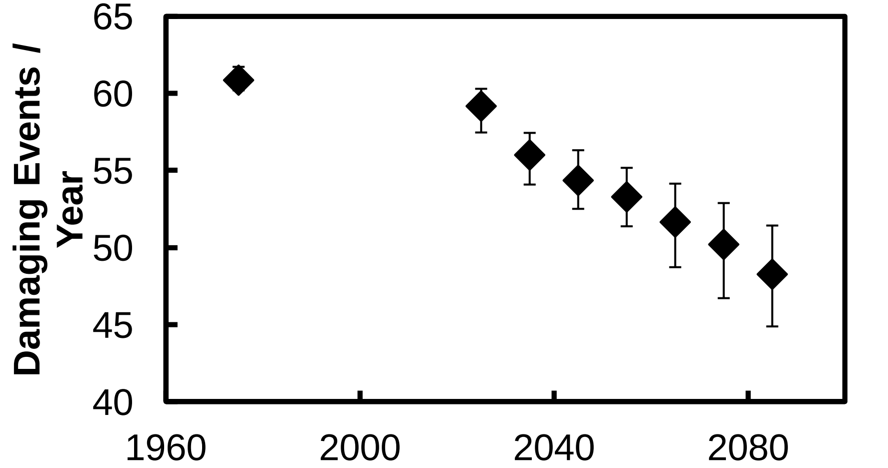


Figure D39: Impact of climate change on 10% humidity shocks.

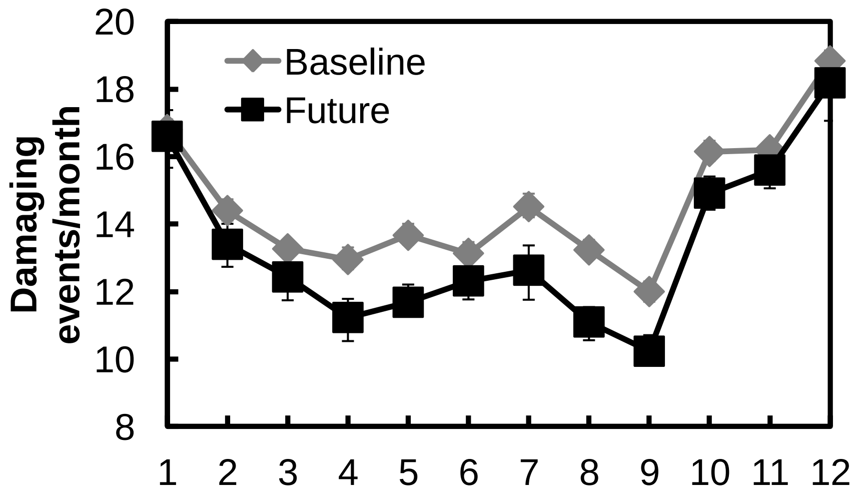


Figure D38: Seasonal impact of climate change on 5% humidity shocks.

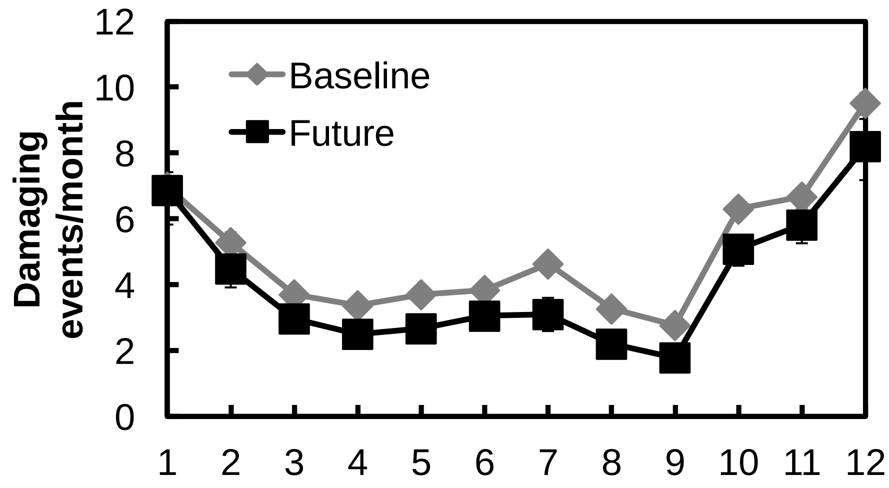


Figure D40: Seasonal impact of climate change on 10% humidity shocks.

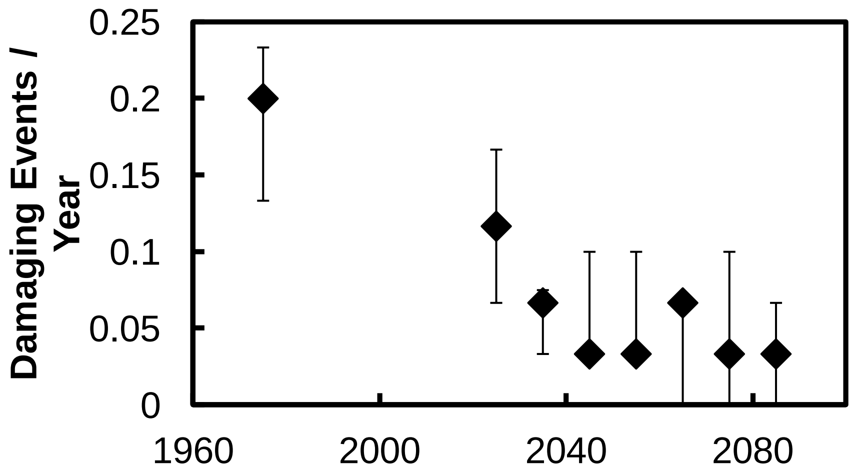


Figure D41: Impact of climate change on 30% humidity shocks.

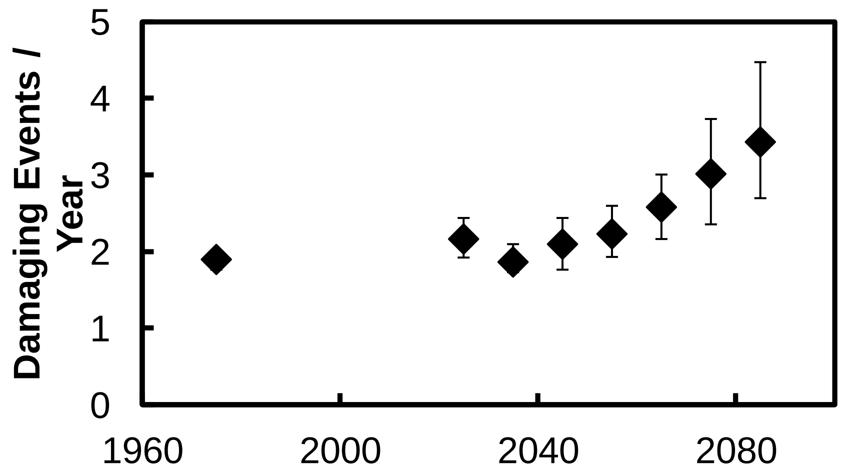


Figure D43: Impact of climate change on Cotton Wood adsorption events.

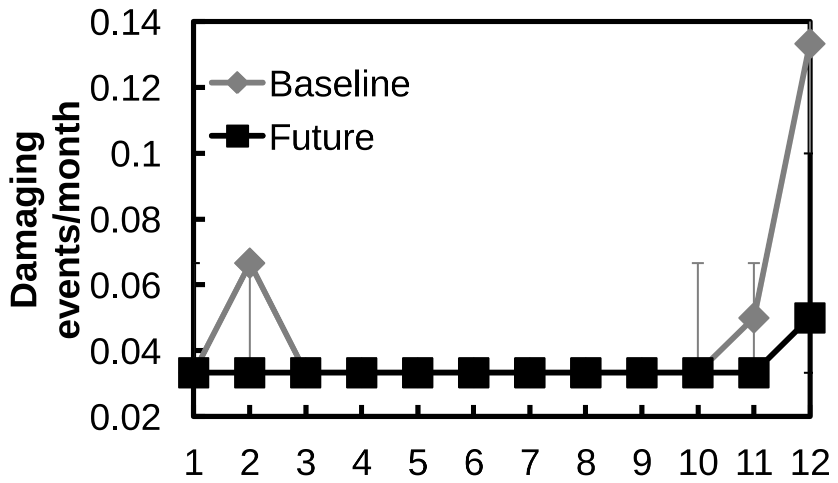


Figure D42: Seasonal impact of climate change on 30% humidity shocks.

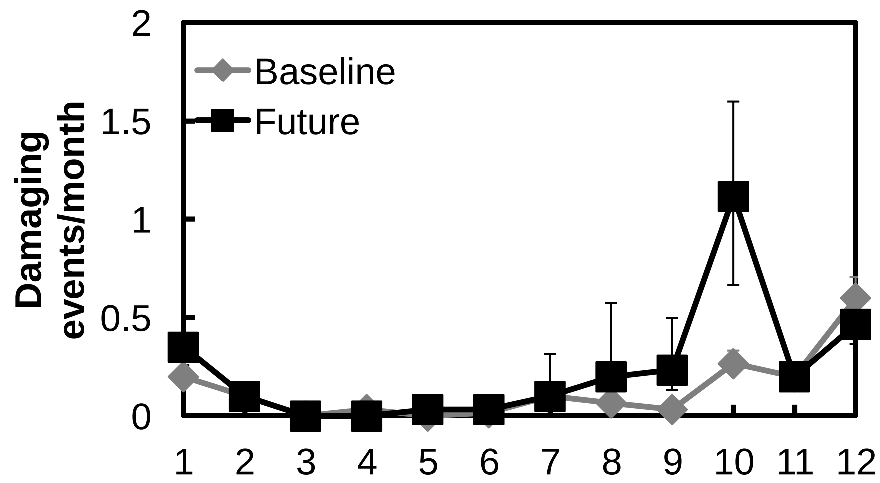


Figure D44: Seasonal impact on Cotton Wood adsorption events.

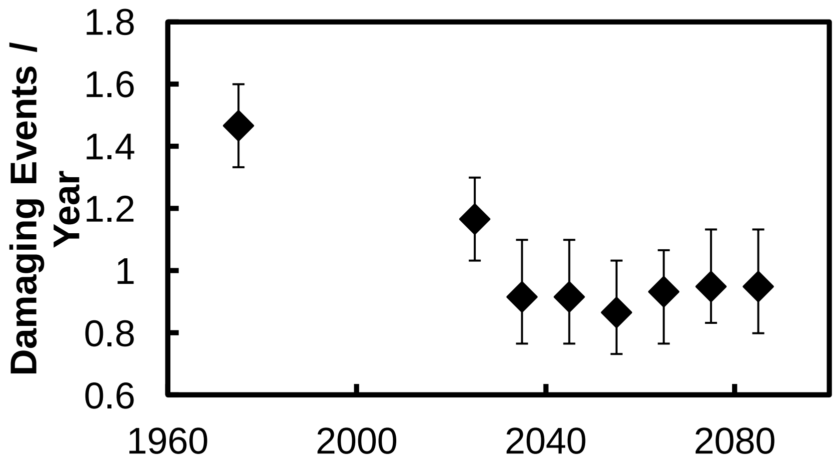


Figure D45: Impact of climate change on Cotton Wood desorption events.

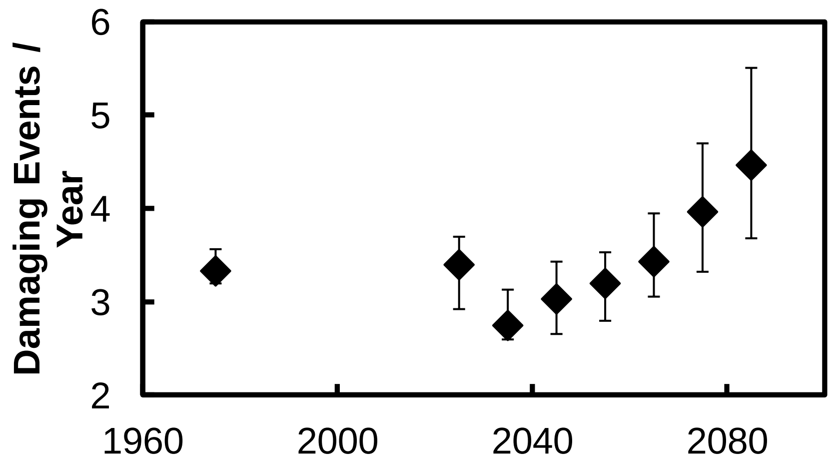


Figure D47: Impact of climate change on Cotton Wood damaging events.

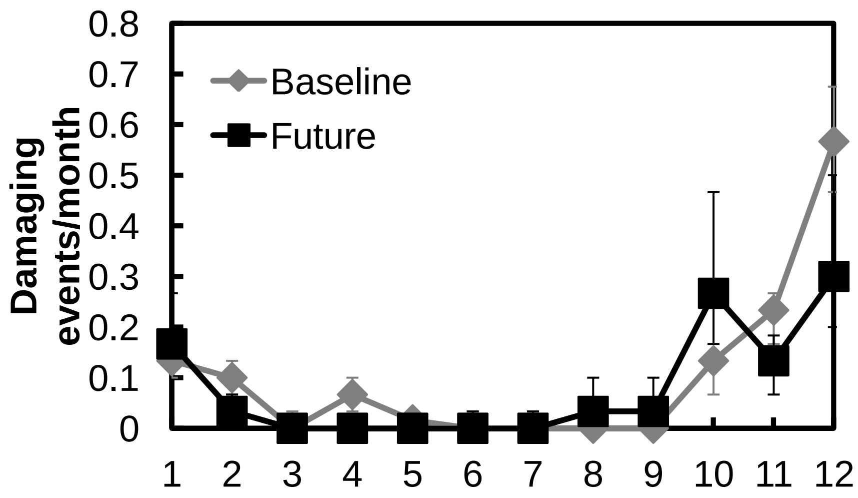


Figure D46: Seasonal impact on Cotton Wood desorption events.

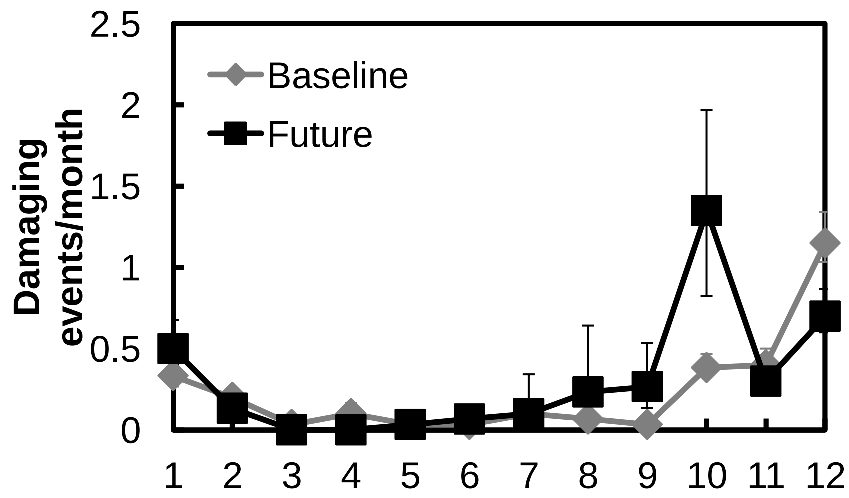


Figure D48: Seasonal impact on Cotton Wood damaging events.

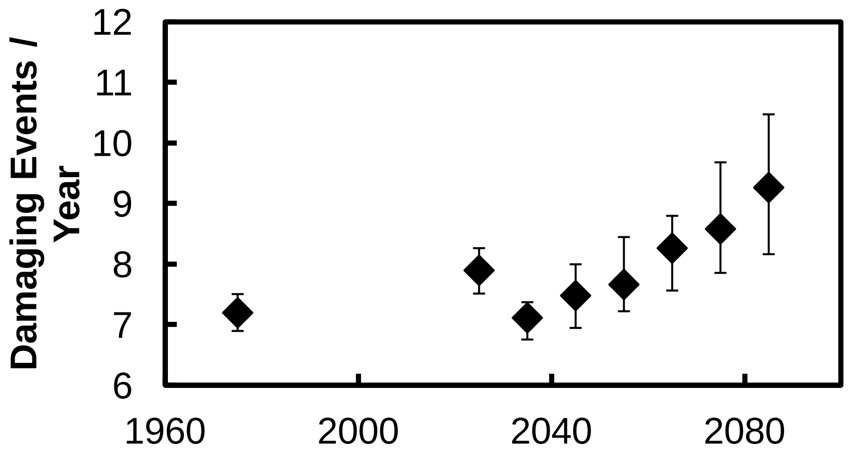


Figure D49: Impact of climate change on White Oak desorption events.

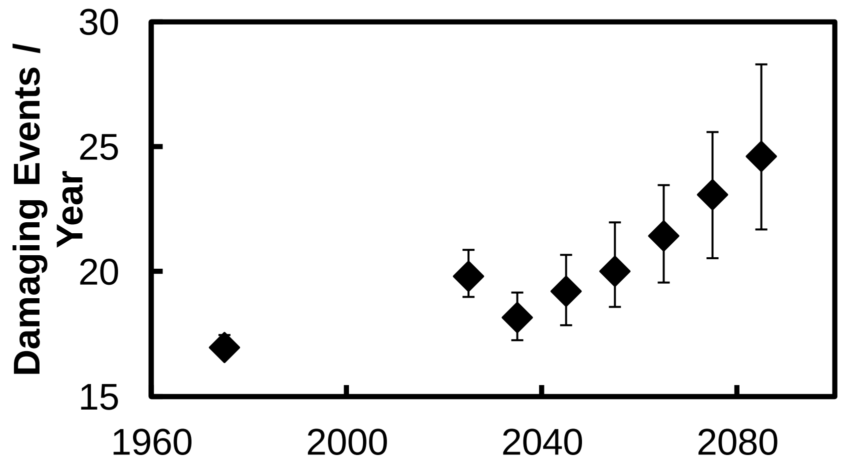


Figure D51: Impact of climate change on White Oak damaging events.

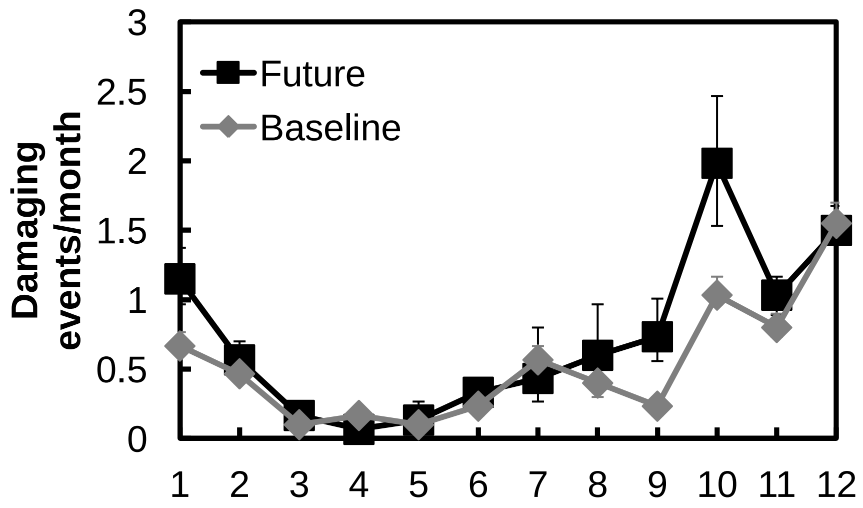


Figure D50: Seasonal impact on White Oak desorption events.

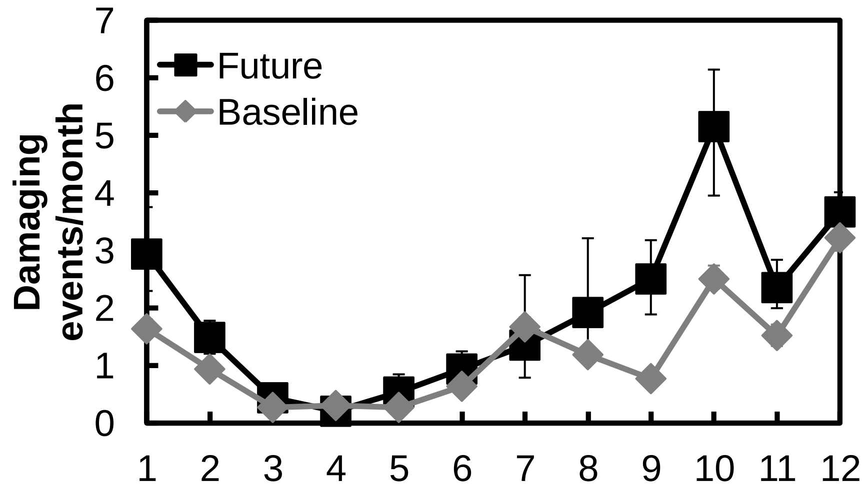


Figure D52: Seasonal impact on White Oak damaging events.

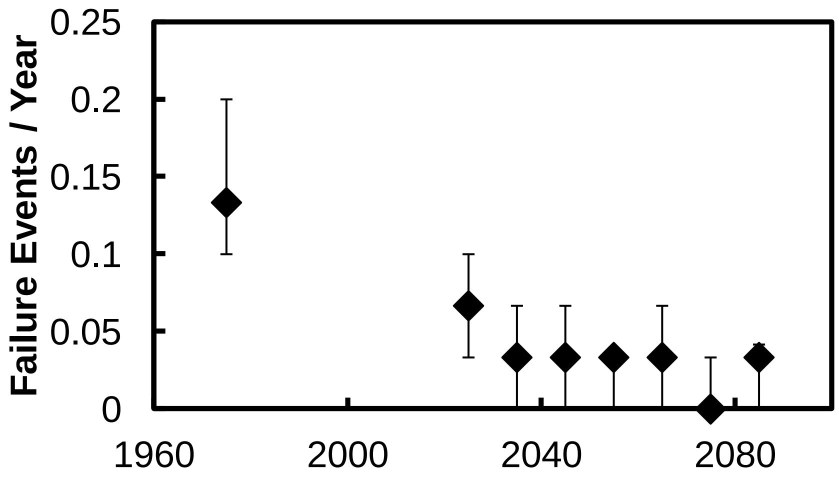


Figure D53: Impact of climate change on White Oak failure events.

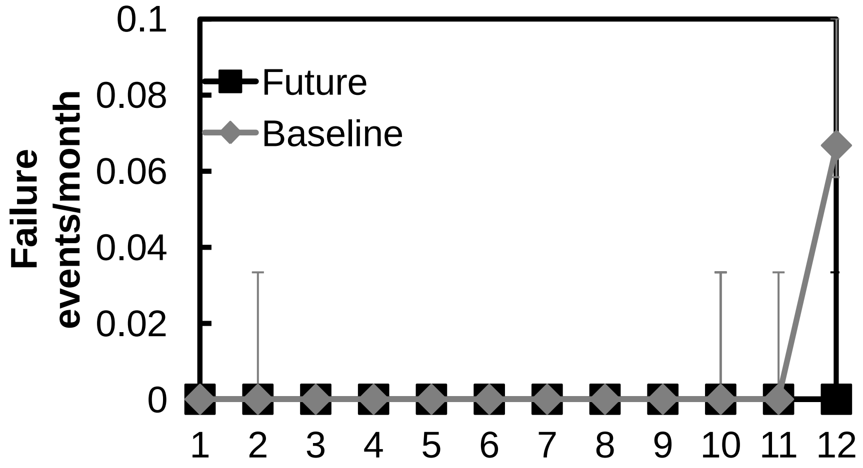


Figure D54: Seasonal impact on White Oak failure events.

Swiss Cottage

Zou

The impact that climate change is projected to have on chemical degradation of paper, as described by the Zou function is shown in figure D55. The rate is projected to increase by more than 50% by the far future; this is likely to have a significant impact on damage to paper within the Swiss Cottage. Statistically the baseline median is significantly different to that of the near future period. The same is also true of the near future median and mid-term future median, and also of the mid-term future and far future median. The seasonal analysis has not been carried out, but due to the dependence of this function on temperature it is likely that the increase is evident in all months.

Silk isoperm

The projected impact of climate change on chemical degradation of silk is shown in figure D56. As with the paper degradation damage function this is also dependent on temperature, thus an increase in the degradation rate is projected. The median of the baseline period is significantly different to that of the near future period. The same is also true of the near future and mid-term future medians, and also the mid-term and far future medians.

5% humidity shock

The impact that climate change is projected to have on dimensional change as described by this function is shown in figure D57. It is projected that the number of damaging events will decrease in the future, however the 10% reduction is unlikely to be significant in terms of damage and preventive conservation measures. Statistically the median of the baseline period is significantly different to the median of the near future period. The same is also true of the near future and mid-term future median, and also the mid-term and far future medians. The seasonal analysis of this damage function is shown in figure D58. It is projected that the overall reduction of damage from this mechanism occurs across all months.

10% humidity shock

The projected impact of climate change on dimensional change of wood, as described by this function is shown in figure D59. As with the previous function there is a reduction in damaging events, in this case by twenty events over the course of the century. While this is unlikely to affect conservation measures significantly, it is possible that it will have a significant reduction on damage caused. Statistically the median of the baseline period is significantly different to that of the near future period. The same is also true of the near future median and mid-term future median, and also of the mid-term and far future medians.

40% humidity shock

The impact that climate change is projected to have on the number of damaging events to wood caused by dimensional change from this damage function is shown in figure D60. A decrease is projected, although for the baseline the risk was negligible anyway. Thus the decrease projected is unlikely to be significant in terms of management strategies. Statistically the baseline period is significantly different to that of the near future period.

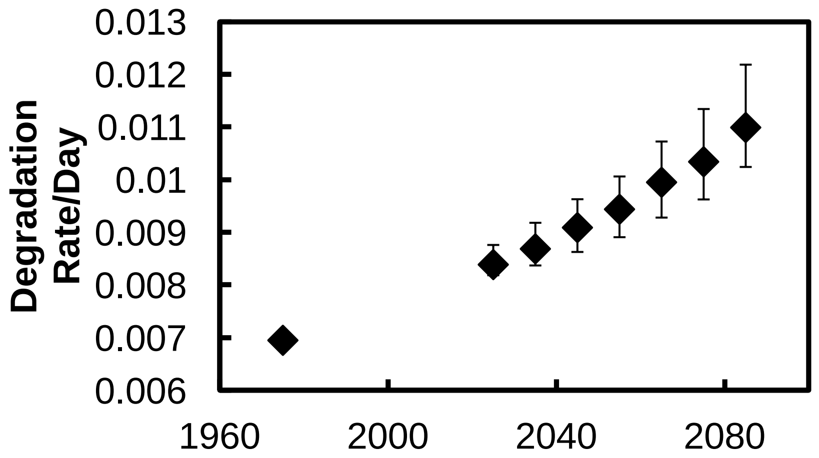


Figure D55: Impact of climate change on the Zou damage function.

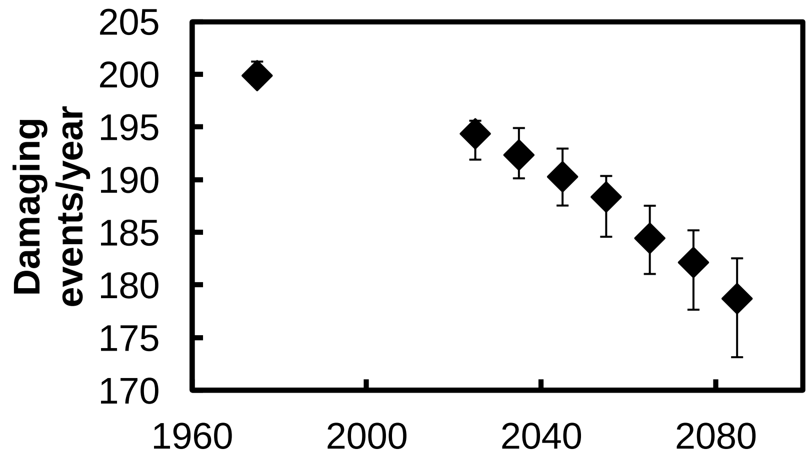


Figure D57: Impact of climate change on 5% humidity shocks.

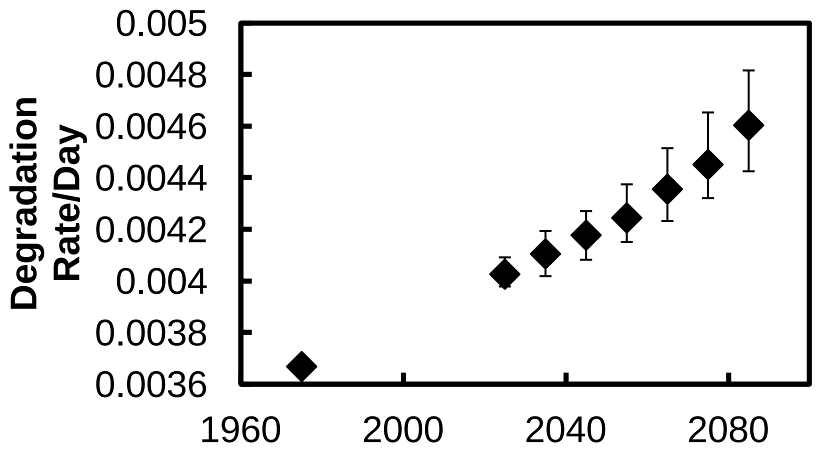


Figure D56: Impact of climate change on the silk damage function.

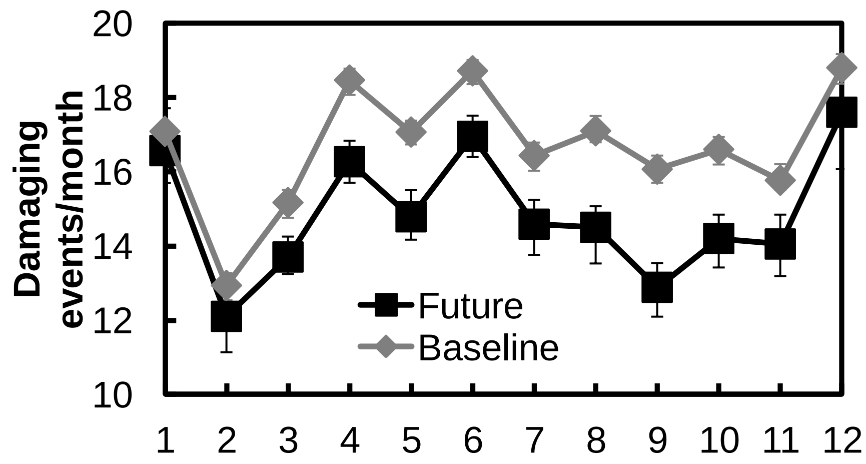


Figure D58: Seasonal impact of climate change on 5% humidity shocks.

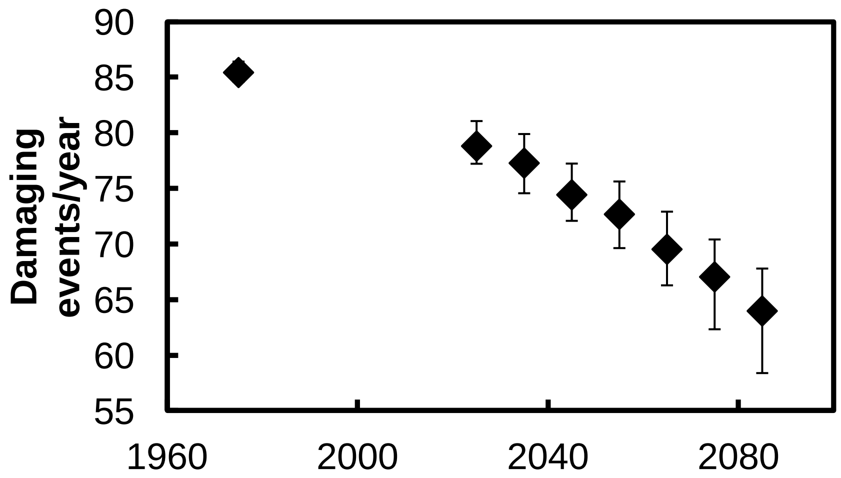


Figure D59: Impact of climate change on 10% humidity shocks.

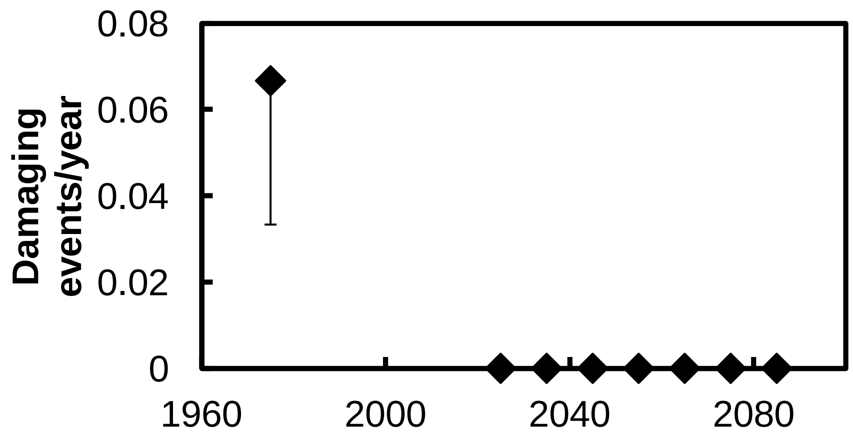


Figure D60: Impact of climate change on 40% humidity shocks.

Location comparison

Daily Average Temperature >20°C

The comparison of the results of this function is shown in figure D61a and b. All locations show a significant increase in days over 20°C.

TWPI

The projected impact of climate change on this paper damage function across three locations is shown in figure D62. The degradation rate increases across all locations, with similar results at each location, the difference in temperature and relative humidity between the Knole locations and Brodsworth Hall appear to have come together resulting in a similar rate of degradation.

Isoperm

The comparison of the results of the Isoperm damage function is shown in figure D63. The results are very similar to that of the TWPI function.

Salt Transitions – 60%

The comparison of the results of this damage function at three locations is shown in figure D64. The Library at Brodsworth Hall is projected to have considerably more transitions than the two Knole rooms; this is due to the relative humidity in the locations, with that in the Library averaging close to the critical relative humidity, and more so in the future.

Salt Transitions – 75.3%

The impact of climate change on this damage function at the locations investigated is shown in figure D65. The difference between the two Knole rooms and the Library at Brodsworth is due to the humidity in the Library being lower than this level, and thus not crossing the critical relative humidity.

Salt Transitions – 85%

The comparison of this damage function across the three locations investigated is shown in figure D66. Again there are no transitions in the Library at Brodsworth Hall, due to the lower level of relative humidity.

5% Humidity Shock

The impact of climate change on this damage function across the four locations investigated is shown in figure D67. A reduction at all locations is projected, a possible reason for differences has been discussed previously.

10% Humidity Shock

The impact of climate change on this damage function across the four locations investigated is shown in figure D68.

30% Humidity Shock

The impact of climate change on this damage function across the four locations investigated is shown in figure D69.

40% Humidity Shock

The impact of climate change on this damage function across the four locations investigated is shown in figure D70.

Cotton Wood Adsorption

The projected impact of climate change on this damage function is shown in figure D71. The projected difference between the Library at Brodsworth Hall and the two Knole rooms is due to the relative humidity difference. The relative humidity in the Library is lower than the other two rooms, and falls into the safe region of the damage function, where more variation in humidity is possible before damage is caused.

Cotton Wood Desorption

The projected impact of climate change on this damage function is shown in figure D72.

Cotton Wood Total

The projected impact of climate change on this damage function is shown in figure D73.

White Oak Adsorption

The projected impact of climate change on this damage function is shown in figure D74.

White Oak Desorption

The projected impact of climate change on this damage function is shown in figure D75.

White Oak Failure

The projected impact of climate change on this damage function is shown in figure D76.

Equilibrium Moisture Content

The projected impact of climate change on this damage function is shown in figure D77. This function is heavily dependent on relative humidity, thus the results correlate well with the relative humidity results.

Isaksson

The projected impact of climate change on this damage function is shown in figure D78. The difference between the two rooms at Knole has been described previously. The results for the Library are due to the relative humidity being well below that required for mould growth.

Critical Relative Humidity

The projected impact of climate change on this damage function is shown in figure D79.

Hukka

The projected impact of climate change on this damage function is shown in figure D80.

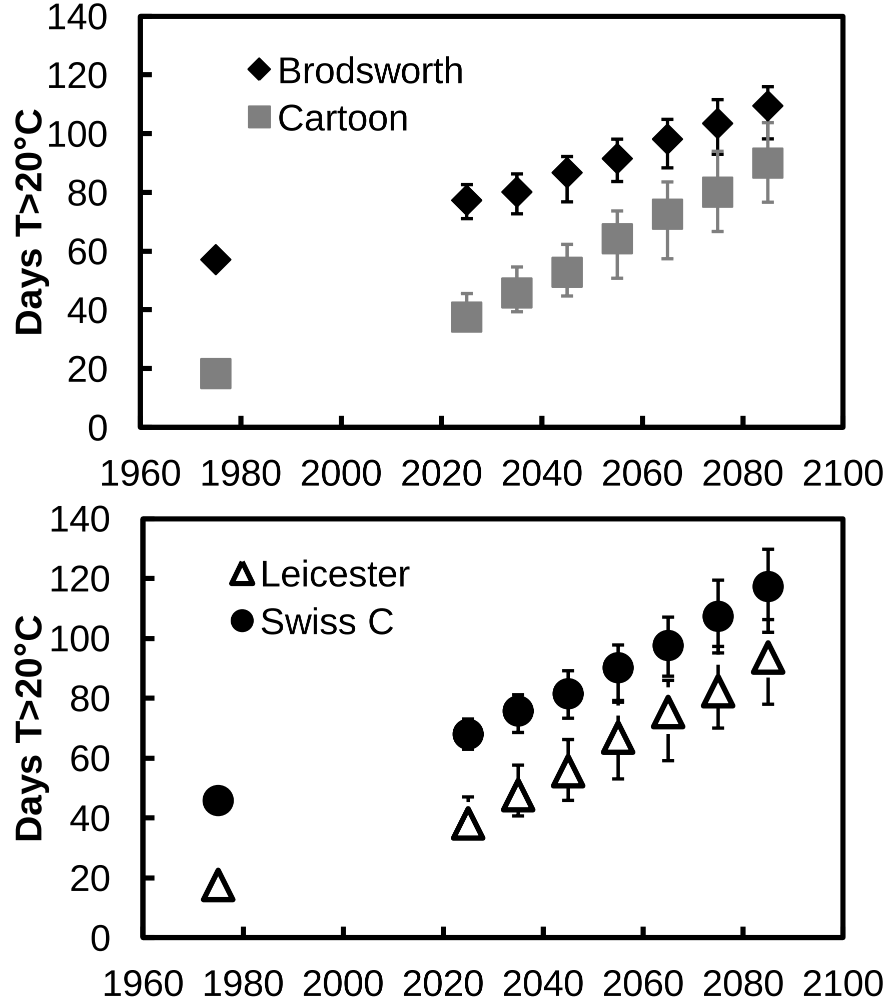


Figure D61 a and b: Impact of climate change on days where the temperature >20°C. Split here for clarity.

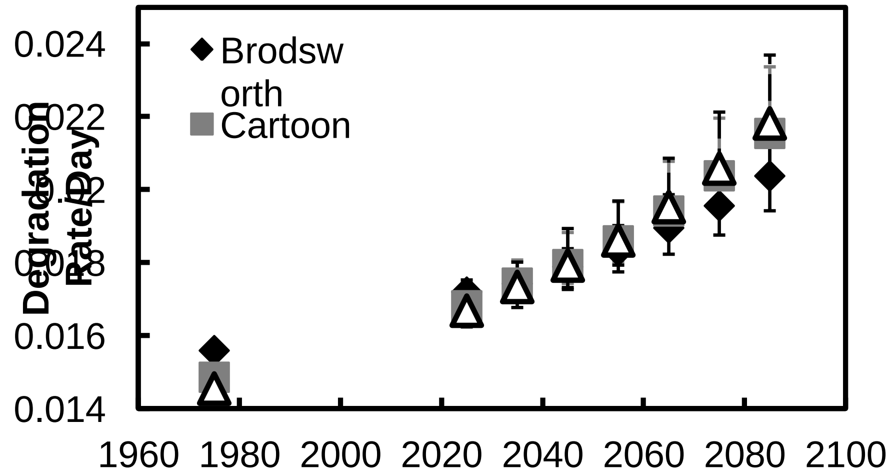


Figure D62: Impact of climate change on the TWPI damage function.

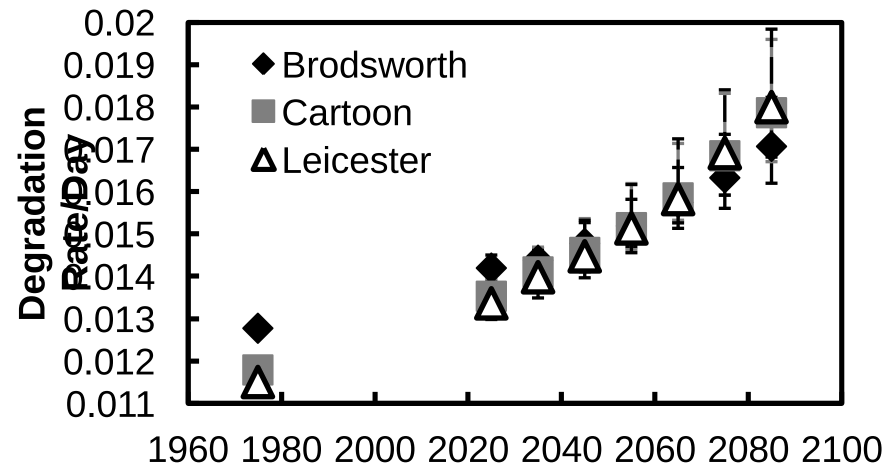


Figure D63: Impact of climate change on the isoperm damage function.

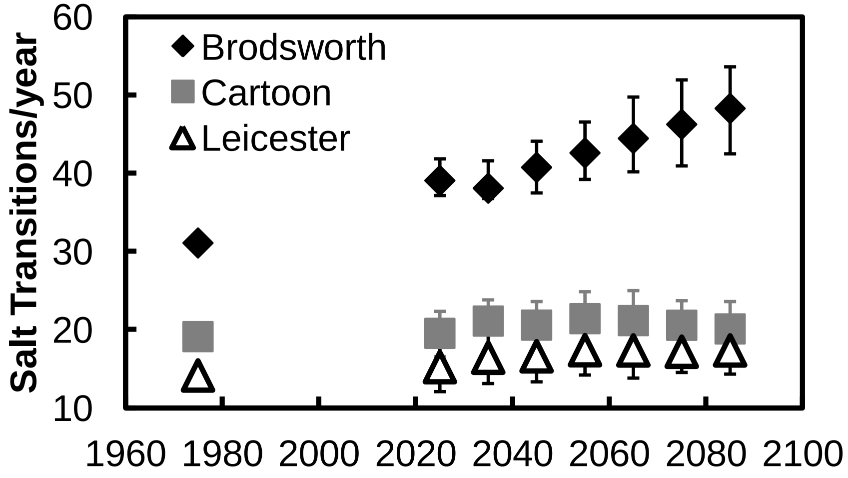


Figure D64: Impact of climate change on 60% salt transitions.

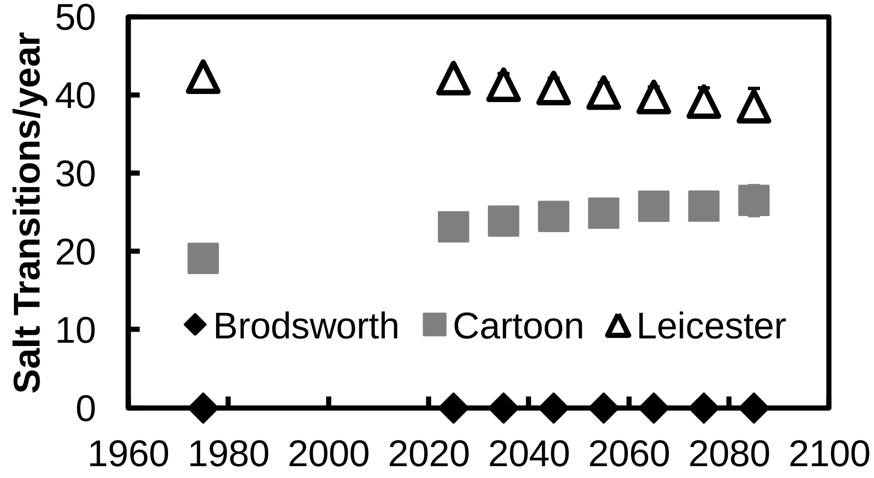


Figure D66: Impact of climate change on 85% salt transitions.

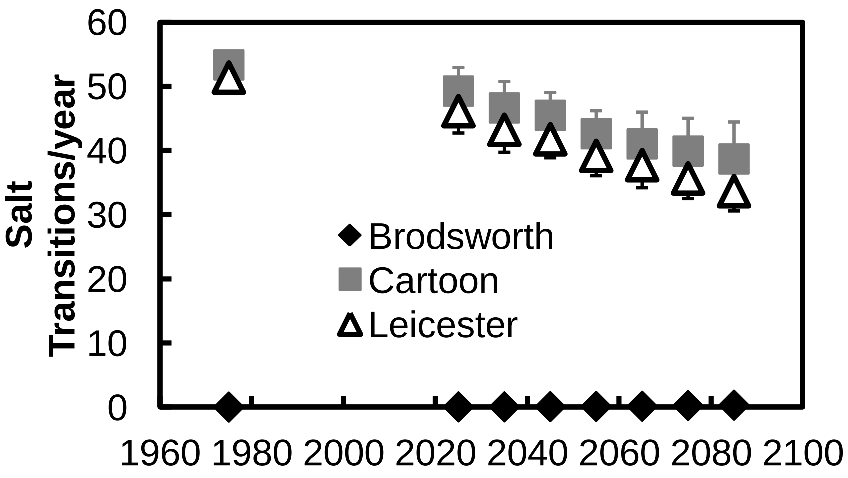


Figure D65: Impact of climate change on 75.3% salt transitions.

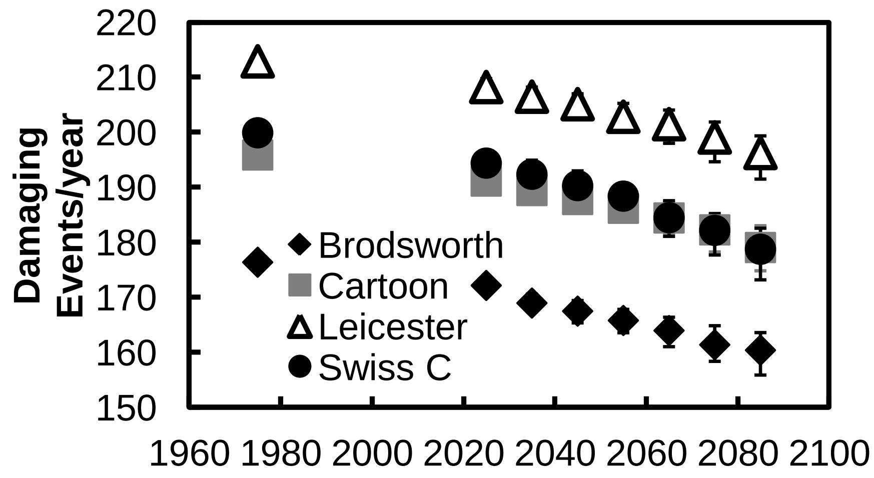


Figure D67: Impact of climate change on 5% humidity shocks.

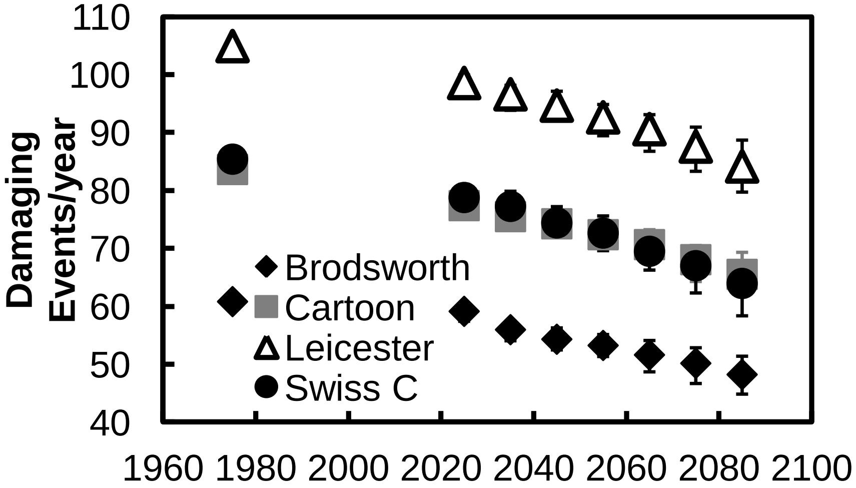


Figure D68: Impact of climate change on 10% humidity shocks.

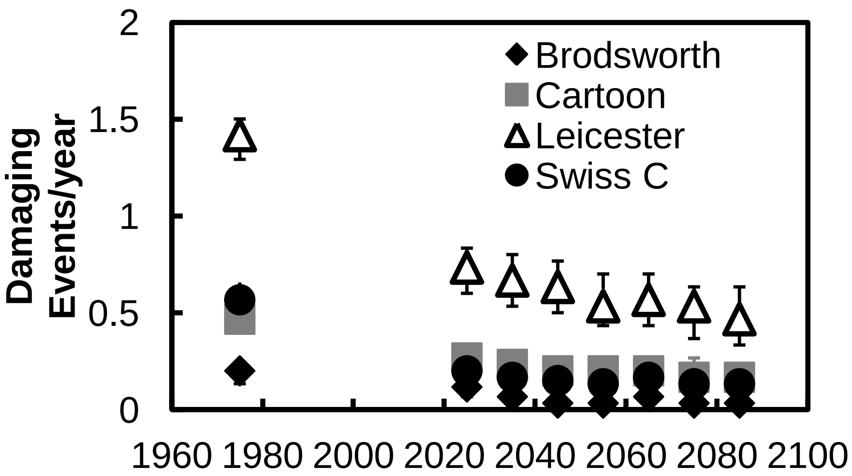


Figure D69: Impact of climate change on 30% humidity shocks.

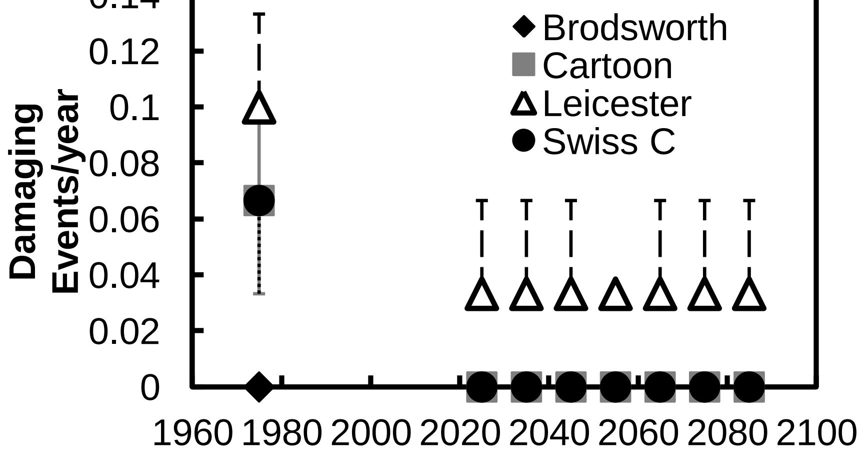


Figure D70: Impact of climate change on 40% humidity shocks.

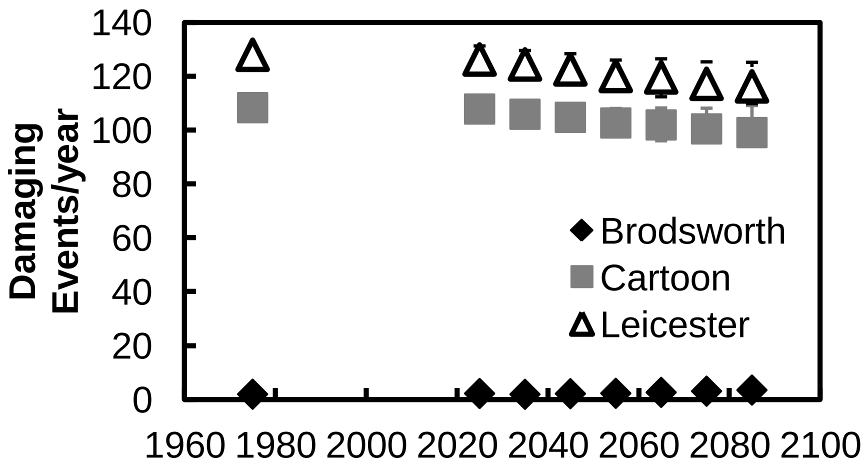


Figure D71: Impact of climate change on Cotton Wood adsorption events.

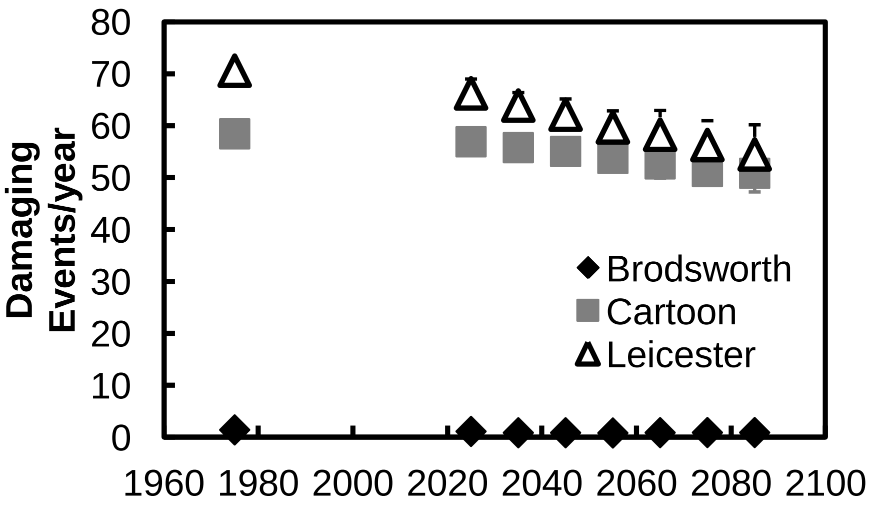


Figure D72: Impact of climate change on Cotton Wood desorption events.

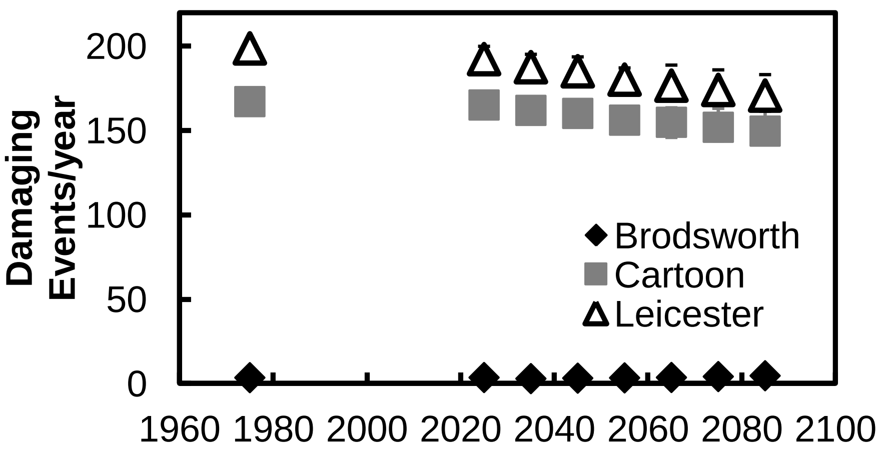


Figure D73: Impact of climate change on Cotton Wood damaging events.

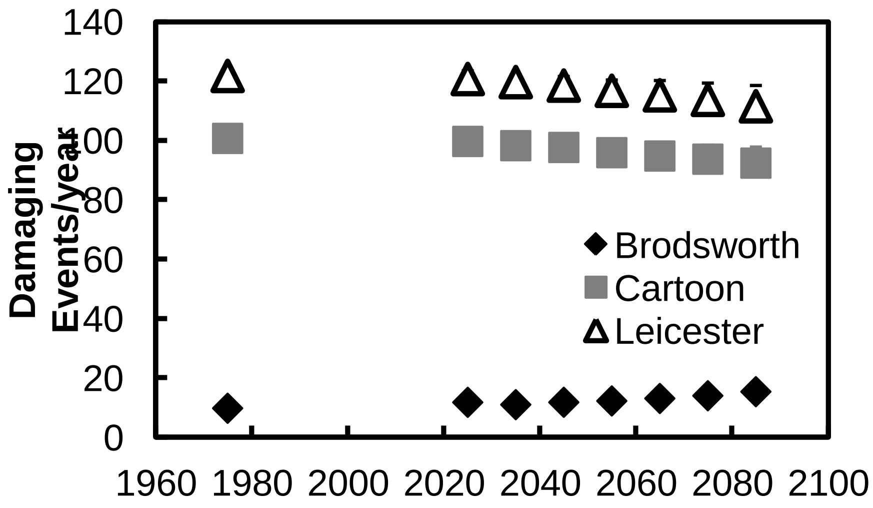


Figure D74: Impact of climate change on White Oak adsorption events.

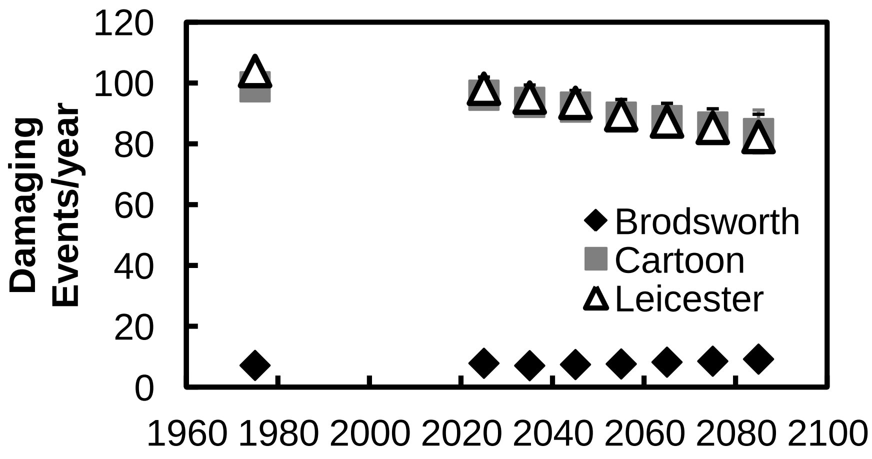


Figure D75: Impact of climate change on White Oak desorption events.

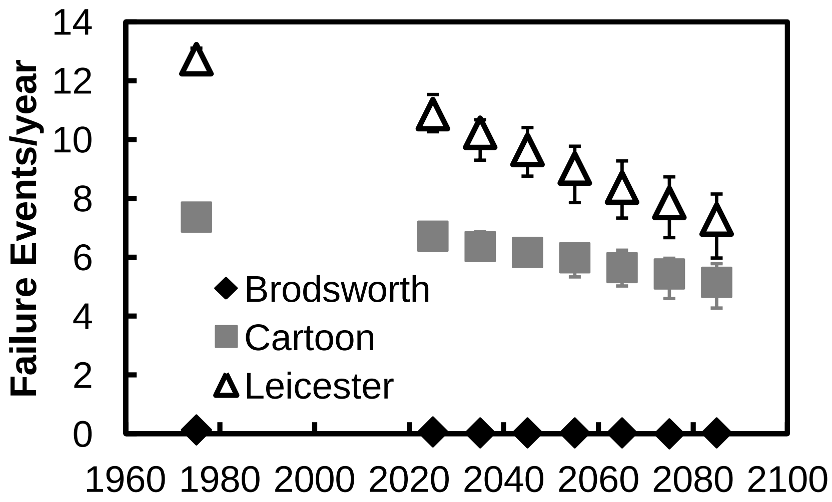


Figure D76: Impact of climate change on White Oak failure events.

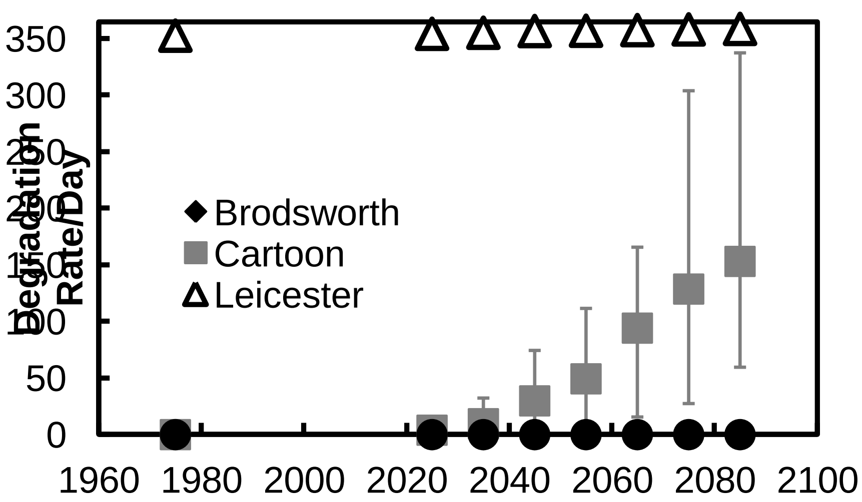


Figure D78: Impact of climate change on the Isaksson damage function.

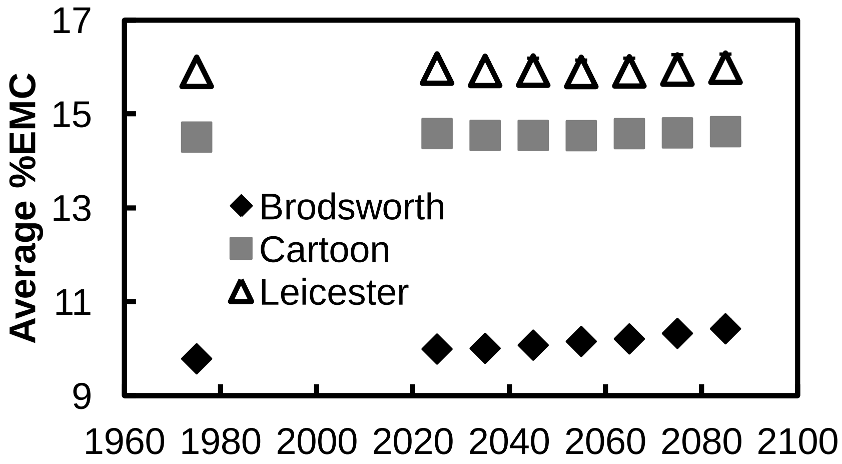


Figure D77: Impact of climate change on equilibrium moisture content.

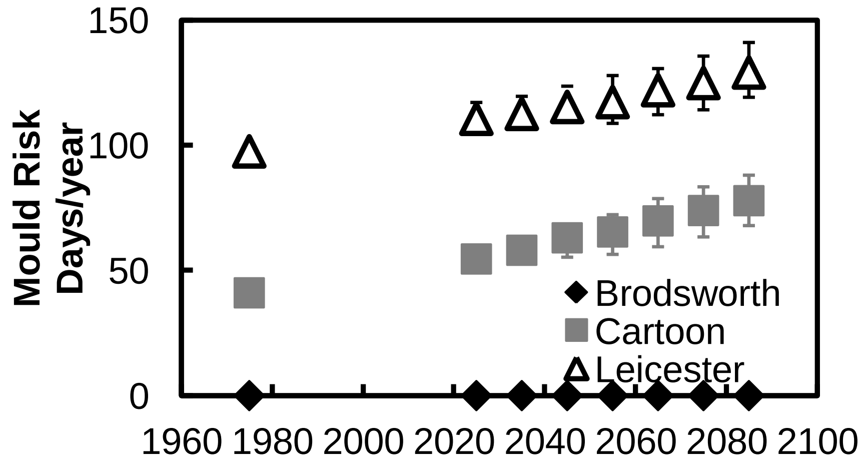


Figure D79: Impact of climate change on the critical RH damage function.

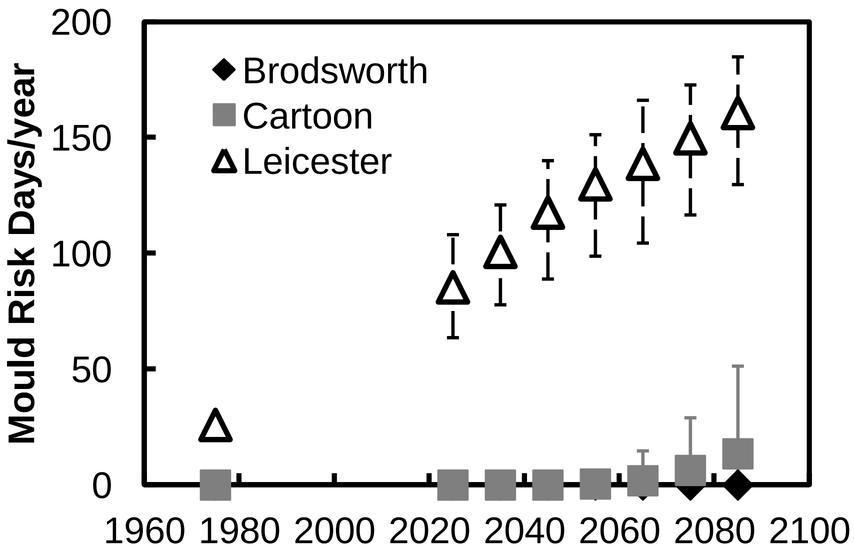


Figure D80: Impact of climate change on the Hukka damage function.

APPENDIX E

AWK PROGRAMS

Introduction to AWK

AWK is a computer programming language, the original version was written in 1977 (Robbins, 2001), and there have been various versions since, with new AWK used here. The AWK name comes from the initials of the original designers, Alfred V. Aho, Peter J. Weinberger and Brain W. Kernighan (Robbins, 2001). AWK use is uncommon in recent years, however it can be an extremely powerful tool when working with text files and carrying out repetitive tasks on large data sets, as used here. It is also very quick as it has no internal memory, so one line of input data is read in, the command executed, and then moves onto the next line, forgetting the previous line. This can present some problems, but usually some logical thinking can solve these issues, and it is possible to build in some memory if required.

AWK is a UNIX based language, so on a unix machine awk should be present, however it is possible to also run it from a computer running windows, it is also available in Mac operating systems as they are based on UNIX. In windows an executable command is required, this sits in the working folder. In command prompt you must first navigate to the folder in which you wish to work, using cd followed by the file path for example: C:\users.......see figure E1 for an example screen shot. Once in the correct folder the name of the executable program is typed, here this is *awk95*, although it can be renamed to anything. This is followed by *–f*, this means that the script of the program is described in the following file, which is then typed, for example *print.awk*. Next the input data file is entered, for example *a.out*, this could also be a .txt or .dat file. An example of a command line is shown in figure E2.

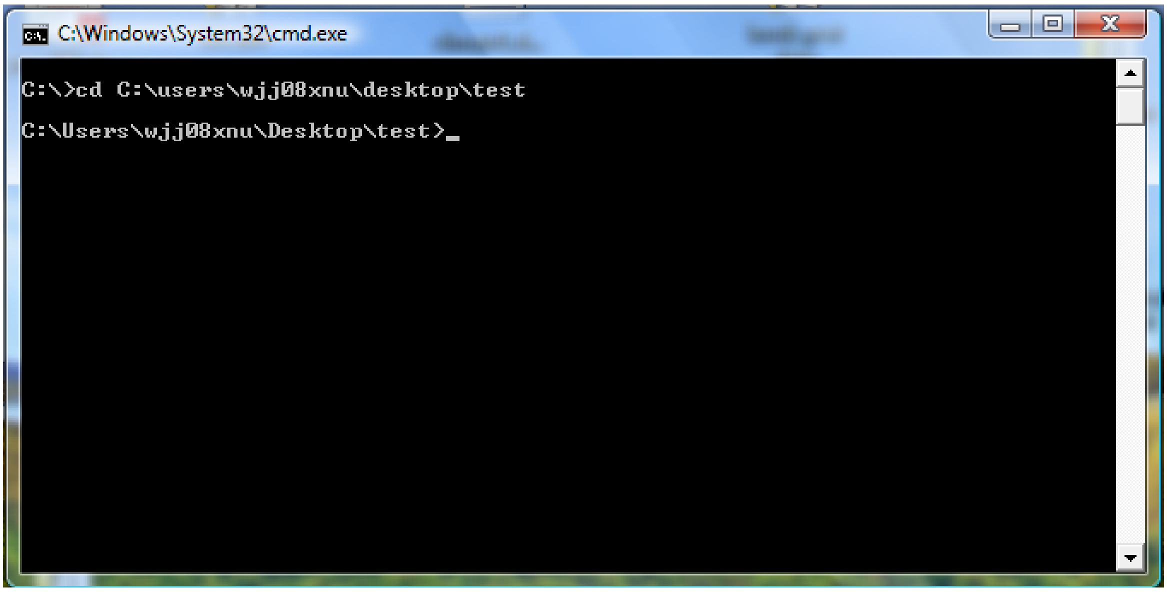


Figure E1: screenshot showing initial command prompt window, the first line navigates to the folder in which to work (C:\users\wjj08xnu\desktop\test). The second line indicates the folder it is now in, and that it is ready for a command.

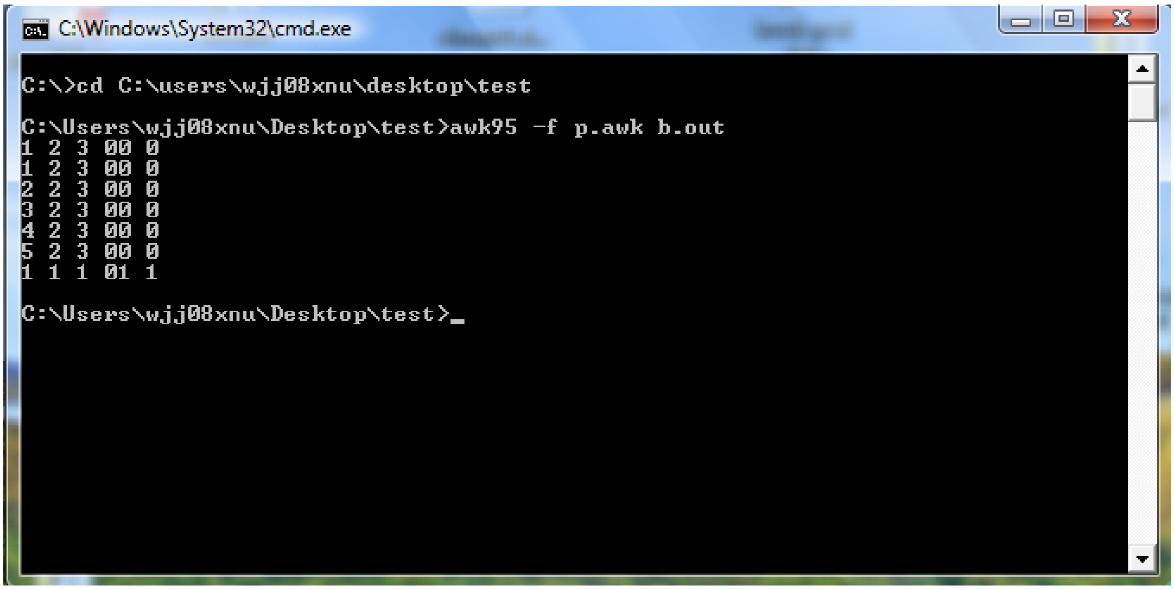


Figure E2: Here the input command is presented, awk95 –f p.awk b.out; after which enter was pressed showing the results of the command, and indicating that it is ready for another input, these results are not saved. (The actual results shown have no meaning; they are part of a test file).

This is the basic requirements, after pressing enter the program will run and the results displayed in the command prompt window. It is possible to save these results however, after the input file name if the symbol > is used this means save, so then a filename is entered, for example results.out, pressing enter now will create, or overwrite a file with the results. It is also possible to append results to an existing file, this uses >>, instead of >. Figure E3 shows an example screen shot of this.

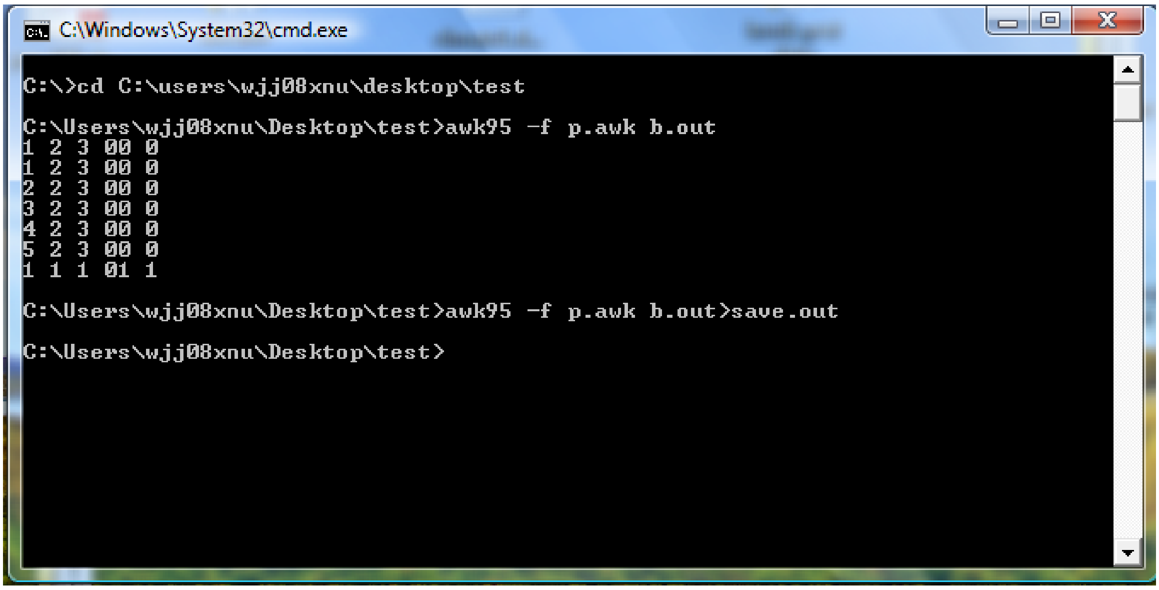


Figure E3: following on from the previous figure, the same command is entered, this time followed by >save.out, this saves the results in a file called save.out.

This gives a brief introduction to the AWK programming language, commonly used operators are described in the following section, after which the AWK programs used throughout the work are presented.

Commands

$	Probably the most important symbol, this means column, so $1 means column 1 and a special use is $0, meaning all columns.
Print	This prints what follows, so print $1,$5 would print columns 1 and 5 on the input file in the output, usually either the command prompt window or the output file. (Technically a function, but included here to help understanding)

FS	Field separator, usually used in form FS="," which would denote a comma separated input file.
BEGIN and END	These describe commands to be executed once only, either at the beginning or end of the file, all other commands in the main body of the program are executed for every input line, unless commands are used to prevent this.
NR	Number of the current record, for example if we are on line 1 of an input file NR=1

Operators:

+=	add the current value to the previous and record the total as the new value. So X+=1 records a new value of X, one larger than previously.
||	Logical OR
&&	Logical AND
*	Multiplication
/	Division
%	Modulus
<	Less than
>=	Greater than or equal to
==	is equal to
!=	Does not equal
^	Exponentiation
++	Increment, standard value +1, also decrement possible with –
#	This is a comment, which is not read by AWK

In built functions:

exp(X)	returns exponential value of X
for (X=1;X=12;X++)	Looping operator, for each value of X, with the initial value 1, and final value 12, with increments of +1 each loop. Something like this may typically be used in a program where months are used.

If (X==1) {do command}

else {do command}	if function, if the statement is true, the value of X is equal to 1 execute the following command. If the statement X==1 is false then execute the else command. It is not always necessary to have an else command.
int(X)	Return the integer value of X, so 1.3, 1.5 and 1.7 all become 1.
sqrt(X)	Returns the square root of X

All of this and a lot more are available in the AWK 'bible' (Robbins, 2001), a version of which is also freely available online at: http://www.gnu.org/software/gawk/manual/gawk.html.

Programs

A variety of the programs used in the work are presented here. Some comments exist within the files, using the # to denote them. Additional comments will be made to start with to help explain the files. These will be in bold and italics.

Climate data

Daily average

This is for data with half hourly observations, a total of 48 per day, if less than 24 are present the average is not reported. Gaps are identified using 'XXX'.

```
BEGIN {S=NC=0}

{

if ($1!="XXX") {S+=$2;NC++}

if ($6=="23:30"){if (NC>=24){Av=S/NC;print $3,$4,$5,Av;S=NC=0}

                    else {print $3,$4,$5,"XXX";S=NC=0}}

}
```

Monthly average

This program was written when my understanding of AWK was basic. It could be shortened from what is shown here.

```
BEGIN
{TS1=TS2=TS3=TS4=TS5=TS6=TS7=TS8=TS9=TS10=TS11=TS12=NC1=NC2=NC3=NC4=NC5=
```

```
NC6=NC7=NC8=NC9=NC10=NC11=NC12=NC1a=NC2a=NC3a=NC4a=NC5a=NC6a=NC7a=NC8a=NC9a=NC10a=NC11a=NC12a=0}

{

if($2=="1"){NC1++;TS1+=$4;if($4=="XXX")NC1a++}

if(NC1==31){Jan=TS1/(NC1-NC1a);print "Jan",Jan,$3;if(NC1a>=15) print "NOT ENOUGH VALUES";NC1=TS1=NC1a=0}

if($2=="2"){TS2+=$4;NC2++;if($4=="XXX") NC2a++}

if(NC2==29){Feb=TS2/(NC2-NC2a);print "Feb",Feb,$3;if(NC2a>=15) print "NOT ENOUGH VALUES";NC2=TS2=NC2a=0}

if($2=="3"){TS3+=$4;NC3++;if($4=="XXX") NC3a++}

if(NC3==31){Mar=TS3/(NC3-NC3a);print "Mar",Mar,$3;if(NC3a>=15) print "NOT ENOUGH VALUES";NC3=TS3=NC3a=0}

if($2=="4"){TS4+=$4;NC4++;if($4=="XXX") NC4a++}

if(NC4==30){Apr=TS4/(NC4-NC4a);print "Apr",Apr,$3;if(NC4a>=15) print "NOT ENOUGH VALUES";NC4=TS4=NC4a=0}

if($2=="5"){TS5+=$4;NC5++;if($4=="XXX") NC5a++}

if(NC5==31){May=TS5/(NC5-NC5a);print "May",May,$3;if(NC5a>=15) print "NOT ENOUGH VALUES";NC5=TS5=NC5a=0}

if($2=="6"){TS6+=$4;NC6++;if($4=="XXX") NC6a++}

if(NC6==30){Jun=TS6/(NC6-NC6a);print "Jun",Jun,$3;if(NC6a>=15) print "NOT ENOUGH VALUES";NC6=TS6=NC6a=0}

if($2=="7"){TS7+=$4;NC7++;if($4=="XXX") NC7a++}

if(NC7==31){Jul=TS7/(NC7-NC7a);print "Jul",Jul,$3;if(NC7a>=15) print "NOT ENOUGH VALUES";NC7=TS7=NC7a=0}

if($2=="8"){TS8+=$4;NC8++;if($4=="XXX") NC8a++}

if(NC8==31){Aug=TS8/(NC8-NC8a);print "Aug",Aug,$3;if(NC8a>=15) print "NOT ENOUGH VALUES";NC8=TS8=NC8a=0}

if($2=="9"){TS9+=$4;NC9++;if($4=="XXX") NC9a++}

if(NC9==30){Sep=TS9/(NC9-NC9a);print "Sep",Sep,$3;if(NC9a>=15) print "NOT ENOUGH VALUES";NC9=TS9=NC9a=0}

if($2=="10"){TS10+=$4;NC10++;if($4=="XXX") NC10a++}

if(NC10==31){Oct=TS10/(NC10-NC10a);print "Oct",Oct,$3;if(NC10a>=15) print "NOT ENOUGH VALUES";NC10=TS10=NC10a=0}

if($2=="11"){TS11+=$4;NC11++;if($4=="XXX") NC11a++}
```

```
if(NC11==30){Nov=TS11/(NC11-NC11a);print "Nov",Nov,$3;if(NC11a>=15) print "NOT ENOUGH VALUES";NC11=TS11=NC11a=0}

if($2=="12"){TS12+=$4;NC12++;if($4=="XXX") NC12a++}

if(NC12==31){Dec=TS12/(NC12-NC12a);print "Dec",Dec,$3;if(NC12a>=15) print "NOT ENOUGH VALUES",NC12a" Missing (above)";NC12=TS12=NC12a=0}

}

#$2=day      $2=month $3=year $4=variable      Data files need 29days in feb
```

Hadley calibration

The calibration values shown here would change from location to location, depending upon the defined calibration between observed and Hadley output.

```
{

if($4=="1"){T=$1+2.1075;RH=$2*0.952128707;print T,RH,$3,$4,$5;T=RH=0}

if($4=="2"){T=$1+0.88281;RH=$2*0.94183875;print T,RH,$3,$4,$5;T=RH=0}

if($4=="3"){T=$1+0.40843;RH=$2*0.92610797;print T,RH,$3,$4,$5;T=RH=0}

if($4=="4"){T=$1+1.08012;RH=$2*0.91697617;print T,RH,$3,$4,$5;T=RH=0}

if($4=="5"){T=$1+1.6995;RH=$2*0.962138554;print T,RH,$3,$4,$5;T=RH=0}

if($4=="6"){T=$1+1.2242;RH=$2*0.965779826;print T,RH,$3,$4,$5;T=RH=0}

if($4=="7"){T=$1+1.2685;RH=$2*0.970937231;print T,RH,$3,$4,$5;T=RH=0}

if($4=="8"){T=$1+1.1363;RH=$2*0.968674171;print T,RH,$3,$4,$5;T=RH=0}

if($4=="9"){T=$1-0.2954;RH=$2*0.950324021;print T,RH,$3,$4,$5;T=RH=0}

if($4=="10"){T=$1+1.85263;RH=$2*0.982621644;print T,RH,$3,$4,$5;T=RH=0}

if($4=="11"){T=$1-0.64316;RH=$2*0.93735834;print T,RH,$3,$4,$5;T=RH=0}

if($4=="12"){T=$1+2.63664;RH=$2*0.950230731;print T,RH,$3,$4,$5;T=RH=0}

}

#T      RH
```

Building simulation

Specific humidity

```
BEGIN{A=-27405.526;B=97.5413;C=-0.146244;D=0.00012558;E=-0.000000048502;F=4.34903;G=0.0039381;R=22105649.25}
```

```
{
T=273.15+$4;RH=$5
if(T>273.15){X=(A+(B*T)+(C*(T^2))+(D*(T^3))+(E*(T^4)))/((F*T)-(G*(T^2)))
Y=exp(X)
Z=Y*R
Pv=(RH/100)*Z
SH=(0.6219*Pv)/(101325-Pv)
if(SH==0)SH="XXX"}
else{X=31.9602-(6270.3605/T)-(0.46057*(log(T)))
        Y=exp(X)
        Pv=(RH/100)*Y
        AH=(0.6219*Pv)/(101325-Pv)
        if(SH==0)AH="XXX"}
print $1,$2,$3,$4,SH
}
```

Relative humidity

```
BEGIN{
#FS=","
A=-27405.526;B=97.5413;C=-0.146244;D=0.00012558;E=-
0.000000048502;F=4.34903;G=0.0039381;R=22105649.25}
{
TC=$4+273.15;RHC=$5

Xa=(A+(B*TC)+(C*(TC^2))+(D*(TC^3))+(E*(TC^4)))/((F*TC)-(G*(TC^2)))
Ya=exp(Xa)
Za=Ya*R
oa=(101325*RHC)/(RHC+0.6219)
m1=oa/Za
print $1,$2,$3,$4,m1*100;RHc=Tc=m1=RHC=TC=0
```

```
}
```

Dew point

```
BEGIN{a=17.271;b=237.7}
{
T=$1;RH=$2

if ($1!="XXX"){
g=((a*T)/(b+T))+log(RH/100)
Td=(b*g)/(a-g)
}
else Td="XXX"
print $1,Td,$2,$3,$4,$5,$6
}
```

Smoothing function

```
BEGIN {for(h=1;h<=95;h++) {A[h]=0};for (i=1;i<=96;i++) {EF[i]=(exp(-((97-i)/96)))}}
{
A[96]=$2
for (j=1;j<=96;j++) {if(A[j]!="XXX") {B+=(EF[j]*A[j]);EFS+=EF[j]}}
                    if(EFS==0){RH="XXX"}
          else {RH=B*(1/EFS)}
if((EFS)>=30){print RH,$3,$4,$5,$6;RH=EFS=B=0}
else print "XXX",$3,$4,$5,$6;RH=EFS=B=0
for (k=1;k<=96;k++) {A[k]=A[k+1]}
}
```

Triangle filter

```
BEGIN{nc=0}
```

```
{

C[1]=C[2];C[2]=C[3];C[3]=C[4];C[4]=C[5];C[5]=C[6];C[6]=C[7];C[7]=C[8];C[8]=C[9];C[9]=C[10];C[10]=C[11];C[11]=C[12];C[12]=C[13];C[13]=C[14];C[14]=C[15];C[15]=C[16];C[16]=C[17];C[17]=C[18];C[18]=C[19];C[19]=C[20];C[20]=C[21];C[21]=C[22];C[22]=C[23];C[23]=C[24];C[24]=C[25];C[25]=C[26];C[26]=C[27];C[27]=C[28];C[28]=C[29];C[29]=C[30];C[30]=C[31];C[31]=C[32];C[32]=C[33];C[33]=C[34];C[34]=C[35];C[35]=C[36];C[36]=C[37];C[37]=C[38];C[38]=C[39];C[39]=C[40];C[40]=C[41];C[41]=C[42];C[42]=C[43];C[43]=C[44];C[44]=C[45];C[45]=C[46];C[46]=C[47];C[47]=C[48];C[48]=$2

nc++

if(nc<49) {print $1,"XXX",$3,$4,$5,$6,$7;pRH=0}

else{

for (a=1;a<=48;a++) {pRH+=(C[a]*((49-a)/1176))}

for (v=1;v<=48;v++) {if(C[v]=="XXX") pRH="XXX"}


print $1,pRH,$3,$4,$5,$6,$7;pRH=0}

}
```

Determine linear regression equations

```
{

for(M=1;M<=12;M++){

if($2==M){if($4!="XXX"){if($5!="XXX"){NC[M]++;xy[M]=$4*$5;xx[M]=$4*$4;yy[M]=$5*$5;x[M]+=$4;y[M]+=$5;Sxy[M]+=xy[M];Sxx[M]+=xx[M];Syy[M]+=yy[M]}}}

}

}

END{for(M=1;M<=12;M++){B[M]=((NC[M]*Sxy[M])-(x[M]*y[M]))/((NC[M]*Sxx[M])-(x[M]*x[M]));A[M]=(y[M]-(B[M]*x[M]))/NC[M];print "y="B[M]"x+"A[M],"M="M}}
```

Indoor relative humidity calibration (Dining room to Library)

```
BEGIN{

a[1]=0.750477;a[2]=0.811697;a[3]=0.832943;a[4]=0.854189;a[5]=0.863478;a[6]=0.863712;a[7]=0.854175;a[8]=0.835421;a[9]=0.85279;a[10]=0.813205;a[11]=0.776049;a[12]=0.739063;}


{

RH=$5
```

```
for (b=1;b<=12;b++){

if ($2==b){RHc=RH*a[b]}

}

print $1,$2,$3,RHc

}
```

Standard transfer function

The calibration values are specific to each location.

```
BEGIN{

FS=","

A=-27405.526;B=97.5413;C=-0.146244;D=0.00012558;E=-
0.000000048502;F=4.34903;G=0.0039381;R=22105649.25

#above for AH conversion. below for T and AH calibration


P[1]=0.541176;P[2]=0.548658;P[3]=0.574391;P[4]=0.639885;P[5]=0.721381;P[6]=0.613286;P[7]=0
.667115;P[8]=0.712569;P[9]=0.639438;P[10]=0.643913;P[11]=0.513634;P[12]=0.424594

Q[1]=4.08598;Q[2]=5.24203;Q[3]=4.91926;Q[4]=5.69714;Q[5]=5.69072;Q[6]=8.36748;Q[7]=7.5501
3;Q[8]=7.95387;Q[9]=7.9305;Q[10]=6.55474;Q[11]=5.68333;Q[12]=4.94195

Pr[1]=0.746236;Pr[2]=0.532753;Pr[3]=0.665744;Pr[4]=0.776119;Pr[5]=0.800856;Pr[6]=0.665806;Pr
[7]=0.735607;Pr[8]=0.799168;Pr[9]=0.718343;Pr[10]=0.921896;Pr[11]=0.645659;Pr[12]=0.656974

Qr[1]=0.0014715;Qr[2]=0.00262318;Qr[3]=0.00196008;Qr[4]=0.00144392;Qr[5]=0.00156117;Qr[6]
=0.00270725;Qr[7]=0.00214249;Qr[8]=0.00198521;Qr[9]=0.00222155;Qr[10]=0.000647228;Qr[11]
=0.00211519;Qr[12]=0.0018546}


{

#below is to convert RH to AH

T=(($7+$8)/2)+273.15;RH=$10*100


if(T>273.15){X=(A+(B*T)+(C*(T^2))+(D*(T^3))+(E*(T^4)))/((F*T)-(G*(T^2)))

Y=exp(X)

Z=Y*R

Pv=(RH/100)*Z
```

```
AH=(0.6219*Pv)/(101325-Pv)
if(AH==0)AH="XXX"}
else{X=31.9602-(6270.3605/T)-(0.46057*(log(T)))
        Y=exp(X)
        Pv=(RH/100)*Y
        AH=(0.6219*Pv)/(101325-Pv)
        if(AH==0)AH="XXX"}
}
{
#below is to transfer indoors
for (Ff=1;Ff<=12;Ff++) {if($2==Ff){
Tc=((T-273.15)*P[Ff])+Q[Ff]
RHc=((AH*Pr[Ff])+Qr[Ff])
TC=Tc+273.15;RHC=RHc

Xa=(A+(B*TC)+(C*(TC^2))+(D*(TC^3))+(E*(TC^4)))/((F*TC)-(G*(TC^2)))
Ya=exp(Xa)
Za=Ya*R
oa=(101325*RHC)/(RHC+0.6219)
m1=oa/Za
print $3,$2,$1,Tc,m1*100;RHc=Tc=m1=RHC=TC=0}}
#above is to convert AH back to RH
}
#T Calibration, linear, Cartoon Gallery and AH calibration when T=$4 RH=$5.
```

Conservation heating transfer function

The calibration values are specific to each location.

```
BEGIN{
FS=","
```

```
A=-27405.526;B=97.5413;C=-0.146244;D=0.00012558;E=-0.000000048502;F=4.34903;G=0.0039381;R=22105649.25

#above for AH conversion. below for T and AH calibration


P[1]=0.541176;P[2]=0.548658;P[3]=0.574391;P[4]=0.639885;P[5]=0.721381;P[6]=0.613286;P[7]=0.667115;P[8]=0.712569;P[9]=0.639438;P[10]=0.643913;P[11]=0.513634;P[12]=0.424594

Q[1]=4.08598;Q[2]=5.24203;Q[3]=4.91926;Q[4]=5.69714;Q[5]=5.69072;Q[6]=8.36748;Q[7]=7.55013;Q[8]=7.95387;Q[9]=7.9305;Q[10]=6.55474;Q[11]=5.68333;Q[12]=4.94195

Pr[1]=0.746236;Pr[2]=0.532753;Pr[3]=0.665744;Pr[4]=0.776119;Pr[5]=0.800856;Pr[6]=0.665806;Pr[7]=0.735607;Pr[8]=0.799168;Pr[9]=0.718343;Pr[10]=0.921896;Pr[11]=0.645659;Pr[12]=0.656974

Qr[1]=0.0014715;Qr[2]=0.00262318;Qr[3]=0.00196008;Qr[4]=0.00144392;Qr[5]=0.00156117;Qr[6]=0.00270725;Qr[7]=0.00214249;Qr[8]=0.00198521;Qr[9]=0.00222155;Qr[10]=0.00647228;Qr[11]=0.00211519;Qr[12]=0.0018546}


{

#below is to convert RH to AH


T=(($7+$8)/2)+273.15;RH=$10*100


if(T>273.15){X=(A+(B*T)+(C*(T^2))+(D*(T^3))+(E*(T^4)))/((F*T)-(G*(T^2)))

Y=exp(X)

Z=Y*R

Pv=(RH/100)*Z

AH=(0.6219*Pv)/(101325-Pv)

if(AH==0)AH="XXX"}

else{X=31.9602-(6270.3605/T)-(0.46057*(log(T)))

        Y=exp(X)

        Pv=(RH/100)*Y

        AH=(0.6219*Pv)/(101325-Pv)

        if(AH==0)AH="XXX"}
```

```
}
{
#below is to transfer indoors
for (Ff=1;Ff<=12;Ff++) {if($2==Ff){
Tc=((T-273.15)*P[Ff])+Q[Ff]
RHc=((AH*Pr[Ff])+Qr[Ff])
TC=Tc+273.15;RHC=RHc

Xa=(A+(B*TC)+(C*(TC^2))+(D*(TC^3))+(E*(TC^4)))/((F*TC)-(G*(TC^2)))
Ya=exp(Xa)
Za=Ya*R
oa=(101325*RHC)/(RHC+0.6219)
m1=oa/Za
RHnew=m1*100}}
#print $3,$2,$1,Tc,m1*100;RHc=Tc=m1=RHC=TC=0}}
#print $3,$2,$1,Tc,RHnew
if(m1>=0.58 && TC<=295.15){

SH=RHC*1000
a=SH/(0.03795*58)
b=log(a)/log(10)
Tc=(237.3*b)/(7.5-b)
RHnew=58

if (Tc>22){Tc=22
TC=Tc+273.15
Xa1=(A+(B*TC)+(C*(TC^2))+(D*(TC^3))+(E*(TC^4)))/((F*TC)-(G*(TC^2)))
Ya1=exp(Xa1)
```

```
Za1=Ya1*R

oa1=(101325*RHC)/(RHC+0.6219)

m1=oa1/Za1

RHnew=m1*100

}

}

print $3,$2,$1,Tc,RHnew

#above is to convert AH back to RH

}

#T Calibration, linear, Cartoon Gallery and AH calibration when T=$4 RH=$5.
```

Damage functions

Each damage function is presented separately, however they formed part of a larger file at one point, which is why each variable is numbered, to make it unique within the larger file. Putting all files into a larger one saves time. The programs presented here were altered to report on a monthly basis, the yearly ones will not be replicated. The damage function itself is the same either way, just how the results are added and reported alter slightly. An indication of how to report yearly will be shown.

Zou

```
#pH=4.85

BEGIN{RHo19[A]=$5;Y19=1961;H19=0.0000141;Aa019=4.54e9;Aa219=2.83e12;Aa519=9.85e16;
Ea19=104000;Lf19=((1/200)-(1/1336))}
```

This file was the 19th of the larger file, hence each variable having 19 after it, to differentiate from the other variables.

```
{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==
07){A=7};if(A==08){A=8};if(A==09){A=9}
```

The section above is for monthly reporting and does not form part of the damage function. An array has been used to run the file for 12 different monthly values. An array variable is denoted by square brackets after, the array used here is called A. The function above actually ensures that the number values are in the correct format, hence there not being 12 values.

T19[A]=$4;RH19[A]=$5 ***this sets the temperature and relative humidity***

```
if(NR==1){RHo19[A]=$5}

if(RH19[A]>=RHo19[A]){
#Adsorption
if(RH19[A]<10){MC19[A]=0.1375*RH19[A]+1.1667}
if((RH19[A]>=10)&&(RH19[A]<=30)){MC19[A]=0.1375*RH19[A]+1.1667}
if((RH19[A]>30)&&(RH19[A]<=60)){MC19[A]=0.0925*RH19[A]+2.4}
if((RH19[A]>60)&&(RH19[A]<=80)){MC19[A]=0.15*RH19[A]-1}
if((RH19[A]>80)&&(RH19[A]<=90)){MC19[A]=0.3*RH19[A]-13}
#if(RH19[A]>90){MC19[A]=0.3*RH19[A]-13}
if(RH19[A]>90){MC19[A]=((0.3*90)-13)+((RH19[A]-90)*2)}
}

if(RH19[A]<RHo19[A]){
#Desorption
if(RH19[A]<10){MC19[A]=0.125*RH19[A]+2.333}
if((RH19[A]>=10)&&(RH19[A]<=30)){MC19[A]=0.125*RH19[A]+2.333}
if((RH19[A]>30)&&(RH19[A]<=60)){MC19[A]=0.115*RH19[A]+2.45}
if((RH19[A]>60)&&(RH19[A]<=80)){MC19[A]=0.2625*RH19[A]+2.45}
if((RH19[A]>80)&&(RH19[A]<=90)){MC19[A]=0.525*RH19[A]-27.25}
#if(RH19[A]>90){MC19[A]=0.525*RH19[A]-27.25}
if(RH19[A]>90){MC19[A]=((0.525*90)-27.25)+((RH19[A]-90)*2)}
}
```

The sections above determine the moisture content to feed into the damage function below.

```
RHo19[A]=$5

B19[A]=(MC19[A]/100)*Aa219
C19[A]=Aa519*H19*(MC19[A]/100)

Aa19[A]=Aa019+B19[A]+C19[A]

Aexp19[A]=exp((Ea19/(8.31*(T19[A]+273.15))))
```

```
Ldays19[A]=(1/Aa19[A])*Aexp19[A]*Lf19

Lyears19[A]=Ldays19[A]/365


Syears19[A]+=1/Lyears19[A]

NC19[A]++


}

END{

for(A=01;A<=12;A++){

print ((Syears19[A]/NC19[A]))}}

#MODIFIED ZOU
```

At the end of the file all the array values from 1-12 are printed to the file.

TWPI

```
BEGIN{Y1=1961;NC1[A]=0}
```

Y1 and following Y variables are remnants from when the files were used with the Hadley data, rather than UCKP. It denotes the start year. While they are defined they are not actually used. Files are typically reused and evolve over time to suit the current application.

```
{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


T1[A]=$4;RH1[A]=$5

rate[A]=RH1[A]*5.9*10^12*exp(-90300/(8.314*(T1[A]+273)))

Srate[A]+=rate[A]

NC1[A]++

}

END{

for(A=01;A<=12;A++){

print (Srate[A]/NC1[A])

}}


#twpi
```

Isoperm

```
BEGIN{Y1=1961;NC1[A]=0;L1=50}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


T1[A]=$4;RH1[A]=$5

Serb[A]=RH1[A]*1.34*10^16*exp(-100000/(8.314*(T1[A]+273)))

sSERB[A]+=Serb[A]

NC1[A]++

}

END{

for(A=01;A<=12;A++){

print ((sSERB[A]/NC1[A])/L1)

}}

#serbera
```

Pretzel

```
BEGIN{Y13=1860;Ea13=100;R13=22105649.25}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


T213[A]=$4+273.15;RH213[A]=$5

T113[A]=293.15;RH113[A]=50


TOP13[A]=(RH113[A]^1.3)*exp(-Ea13/(R13*T113[A]))
```

```
BOT13[A]=(RH213[A]^1.3)*exp(-Ea13/(R13*T213[A]))

Life13[A]=TOP13[A]/BOT13[A]

RATE13[A]=1/Life13[A]


Sum13[A]+=RATE13[A];NC13[A]++

}

END{

for(A=01;A<=12;A++){

print RATE13[A]/NC13[A]}}
```

Silk

```
BEGIN{NC4[A]=0;a4=0.0000082426;e4=0.000000000000502;Y4=1961}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


NC4[A]++


T4[A]=$4;RH4[A]=$5

B4[A]=exp((-50*1000)/(8.314*(T4[A]+273)))

C4[A]=RH4[A]*a4*B4[A]

D4[A]=C4[A]/e4

SI4[A]=250/D4[A]

RuSu[A]+=1/SI4[A]

Y4=$3

}

END{

for(A=01;A<=12;A++){

TWSI[A]=NC4[A]/RuSu[A];print 1/TWSI[A];NC4[A]=1;RuSu[A]=0

}}

#Silk yearly age
```

Thenardite/mirabilite

```
BEGIN{b3=1961;a3[A]=0}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==
07){A=7};if(A==08){A=8};if(A==09){A=9}


T3[A]=$4;RH3[A]=$5;CRIT[A]=0.87549*T[A]+59.11

if ((T3[A]<22.5) && (T3[A]>0) && ((RH3[A]>CRIT[A]) && (RHO[A]<CRITO[A]))){a3[A]=a3[A]+1}

RHO[A]=RH3[A];CRITO[A]=CRIT[A]

#if($3!=b3){print $1,$2,b3,a3;a3=0}

#b3=$3

}

END{

for(A=01;A<=12;A++){

print a3[A]/30;a3[A]=0}}
```

Salt 60

```
BEGIN{y3a=1961;a3a[A]=0}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==
07){A=7};if(A==08){A=8};if(A==09){A=9}


T3a[A]=$4;RH3a[A]=$5; CRITb3a[A]=60

if ((RH3a[A]>CRITb3a[A])&&(RHO3a[A]<CRITb3a[A])){b3a[A]=b3a[A]+1}

RHO3a[A]=RH3a[A]

}

END{

for(A=01;A<=12;A++){


print b3a[A]/30

a3a[A]=b3a[A]=c3a[A]=0
```

```
}}
```

The same process was used for 75.3% and 85%

Humidity Shock

```
BEGIN{RHb14[A]=50;NC14[A]=0;NC114[A]=0;NC214[A]=0;Y14=1960}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


RHa14[A]=$5

c14[A]=sqrt((RHb14[A]-RHa14[A])^2)

if(c14[A]>5){NC14[A]++}

RHb14[A]=RHa14[A]

}

END{

for(A=01;A<=12;A++){

print NC14[A]/30

}}
```

Cotton Wood adsorption

```
#T actually is RH

BEGIN{T17=$5;Y17=1961}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


if($5>=T17){


if((T17>=10)&&(T17<=30)){CritA17=1.5*T17+1}

if((T17>30)&&(T17<=40)){CritA17=T17+18}
```

```
if((T17>40)&&(T17<=50)){CritA17=0.5*T17+38}

if((T17>50)&&(T17<=60)){CritA17=0.4*T17+43}

if((T17>60)&&(T17<=90)){CritA17=0.8*T17+19}


if($5>=CritA17){NC17[A]++}

}


if($5<T17){


if((T17>=10)&&(T17<=30)){CritB17=0.8*T17-3.33}

if((T17>30)&&(T17<=50)){CritB17=0.6*T17+3.33}

if((T17>50)&&(T17<=60)){CritB17=0.9*T17-12}

if((T17>60)&&(T17<=70)){CritB17=2*T17-78}

if((T17>70)&&(T17<=80)){CritB17=1.6*T17-50}

if((T17>80)&&(T17<=90)){CritB17=1.05*T17-6}


if($5<=CritB17){NC117[A]++}

}


#if($3!=Y){print Y,NC,NC1,NC+NC1;NC=NC1=0}


#Y=$3
```

The two lines above relate to yearly average reporting. Note the # to remove them from being used. The first END statement is also for this.

```
T17=$5

}

#END{print NC17/30,NC117/30,(NC17/30+NC117/30)}

END{

for(A=01;A<=12;A++){

print NC17[A]/30

#print NC117[A]

#print (NC17[A]+NC117[A])

}}
```

#MECKLENBERG DIMENSIONAL CHANGE WHITE OAK occurences per year (avg)

This file actually determines both adsorption and desorption events, but only reports adsorption, the same file is run again for desorption events.

White Oak failure

```
#T actually is RH!

BEGIN{T18[A]=$5;Y18=1961}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


if($5<T18[A]){


if((T18[A]>=10)&&(T18[A]<=20)){CritB18[A]=0.8*T18[A]-8}

if((T18[A]>20)&&(T18[A]<=30)){CritB18[A]=0.5*T18[A]-2}

if((T18[A]>30)&&(T18[A]<=40)){CritB18[A]=0.6*T18[A]-5}

if((T18[A]>40)&&(T18[A]<=50)){CritB18[A]=0.2*T18[A]+11}

if((T18[A]>50)&&(T18[A]<=60)){CritB18[A]=0.7*T18[A]-14}

if((T18[A]>60)&&(T18[A]<=70)){CritB18[A]=T18[A]-32}

if((T18[A]>70)&&(T18[A]<=80)){CritB18[A]=2.4*T18[A]-130}

if((T18[A]>80)&&(T18[A]<=90)){CritB18[A]=1.6*T18[A]-66}


if($5<=CritB18[A]){NC118[A]++}

}

T18[A]=$5

}

END{

for(A=01;A<=12;A++){

print NC118[A]/30

}}

#MECKLENBERG DIMENSIONAL CHANGE WHITE OAK FAILURE
```

Daily average temperature >20°C

```
BEGIN{Y15=1961}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==
07){A=7};if(A==08){A=8};if(A==09){A=9}


if($4>20){NC015[A]++}

}

END{

for(A=01;A<=12;A++){

print (NC015[A]/30)

}}

#no days (avg of 30 years) over or under specific temp/rh
```

EMC average

```
BEGIN{Y6=1961}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==
07){A=7};if(A==08){A=8};if(A==09){A=9}


T6[A]=$4;RH6[A]=$5/100

w6[A]=349+(1.29*T6[A])+(0.0135*T6[A]*T6[A])

k6[A]=0.805+(0.000736*T6[A])-(0.00000273*T6[A]*T6[A])

k16[A]=6.27-(0.00938*T6[A])-(0.000303*T6[A]*T6[A])

k26[A]=1.91+(0.0407*T6[A])-(0.000293*T6[A]*T6[A])

A6[A]=k16[A]*k26[A]*k6[A]*k6[A]*RH6[A]*RH6[A]

B6[A]=k16[A]*k6[A]*RH6[A]

C6[A]=k6[A]*RH6[A]

D6[A]=(C6[A]/(1-C6[A]))+((B6[A]+(2*A6[A]))/(1+B6[A]+A6[A]))

E6[A]=1800/w6[A]

MC6[A]=D6[A]*E6[A]
```

```
MCs6[A]+=MC6[A]

NC6[A]++

}

END{

for(A=01;A<=12;A++){

print MCs6[A]/NC6[A]}}

#EMC max and avg
```

Isaksson

```
BEGIN{D9=0;Y9=1961;Dmax9=0}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}



T9=$4;RH9=$5

if(RH9>=75){Drh9=exp(15.53*log(RH9/90))}

if(RH9<60){Drh9=-0.5}

if((RH9>=60)&&(RH9<75)){Drh9=(-2.7+((1.1*RH9)/30))}


if((T9>0.1)&&(T9<=30)){Dt9=exp(0.74*log(T9/20))}


if(T9<0.1){D9+=-0.5}

else{D9+=Drh9*Dt9}


if(D9<0){D9=0}


if(D9/29>=1){a9[A]++}


Y9=$3

}
```

```
END{

for(A=01;A<=12;A++){

print a9[A]

}}

#resets mould after each year. counts days over 1 and reports monthly, but keeps sum going for whole year.

#Mould risk from Issakson paper
```

Critical Relative Humidity

```
BEGIN{y10=1961;a10[A]=0}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


T10[A]=$4;RH10[A]=$5

if(T10[A]<20){RHcrit10[A]=(-0.00267*T10[A]^3)+(0.160*T10[A]^2)-(3.13*T10[A])+100}

else{RHcrit10[A]=80}


if(RH10[A]>=RHcrit10[A]){a10[A]++}

}

END{

for(A=01;A<=12;A++){

print a10[A]/30;a10[A]=0}}

#Mould RHcrit exceedence.
```

Hukka

```
BEGIN{W11=1;SQ11=1;M11=0.0;Mm11=0;Y11=1961;MNC11[A]=0}

{

A=$2

if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}


T11=$4;RH11=$5
```

```
if(T11<20){RHcrit11=(-0.00267*T11^3)+(0.160*T11^2)-(3.13*T11)+100}

else{RHcrit11=80}

Mmax11=1+(7*((RHcrit11-RH11)/(RHcrit11-100)))-(2*((RHcrit11-RH11)/(RHcrit11-100))^2)

Tv11=exp((-0.74*log(T11))-(12.72*log(RH11))+(0.06*W11)+61.5)

Tm11=exp((-0.68*log(T11))-(13.9*log(RH11))+(0.14*W11)-(0.33*SQ11)+66.02)


if(M11>1){K111=2/(Tv11/(Tm11-1))}

else{K111=1}

K211=1-exp(2.3*(M11-Mmax11))


if(RH11>=RHcrit11){dM11=(1/(7*exp((-0.68*log(T11))-(13.9*log(RH11))+(0.14*W11)-
(0.33*SQ11)+66.02)))*K111*K211;time11=0}

else{if(time11==0){dM11=0;time11=1}

        else{dM11=-0.016}}

M11+=dM11

if(M11<=0){M11=0}


if(M11>1){MNC11[A]++}

}

END{

for(A=01;A<=12;A++){

print MNC11[A]/30;Mm11=MNC11[A]=0}}

#Hukka Mould risk. reports occ over 1 per year.
```

Graph method

This is undertaken using two AWK programs, the first assigns the area within which the temperature and relative humidity pair falls, using the fitted ellipse equations. The second then applies the method of calculating the mould growth risk, as described previously.

First program

```
BEGIN{

a1=8.5;b1=4.75;h1=28.5;k1=94;

a2=12;b2=7;h2=28.5;k2=93.5;

a3=14.5;b3=10;h3=24;k3=90;

a4=17;b4=11.5;h4=25.5;k4=90;
```

```
a5=18.5;b5=13;h5=25;k5=90;

a6=19;b6=14;h6=25;k6=90;

PI=3.1415927;M=7}

#########################################################

{

T=$4;RH=$5


cT1=T-h1;cRH1=RH-k1


Th1=9


Tr1=(cT1*cos(PI/Th1))-(cRH1*sin(PI/Th1))


RHr1=(cT1*sin(PI/Th1))+(cRH1*cos(PI/Th1))


Tn=Tr1+h1;RHn=RHr1+k1


RH1max=b1*sqrt(1-((Tn-h1)/a1)^2)+k1

RH1min=-(b1*sqrt(1-((Tn-h1)/a1)^2))+k1


if((RHn<=RH1max)&&(RHn>=RH1min)){M=1}

else{

########################################################

cT2=T-h2;cRH2=RH-k2


Th2=6


Tr2=(cT2*cos(PI/Th2))-(cRH2*sin(PI/Th2))


RHr2=(cT2*sin(PI/Th2))+(cRH2*cos(PI/Th2))


Tn=Tr2+h2;RHn=RHr2+k2
```

```
RH2max=b2*sqrt(1-((Tn-h2)/a2)^2)+k2
RH2min=-(b2*sqrt(1-((Tn-h2)/a2)^2))+k2

if((RHn<=RH2max)&&(RHn>=RH2min)){M=2}
else{
############################################################
cT3=T-h3;cRH3=RH-k3

Th3=3.857
Tr3=(cT3*cos(PI/Th3))-(cRH3*sin(PI/Th3))

RHr3=(cT3*sin(PI/Th3))+(cRH3*cos(PI/Th3))

Tn=Tr3+h3;RHn=RHr3+k3

RH3max=b3*sqrt(1-((Tn-h3)/a3)^2)+k3
RH3min=-(b3*sqrt(1-((Tn-h3)/a3)^2))+k3

if((RHn<=RH3max)&&(RHn>=RH3min)){M=3}
else{
############################################################
cT4=T-h4;cRH4=RH-k4

Th4=3.5
Tr4=(cT4*cos(PI/Th4))-(cRH4*sin(PI/Th4))

RHr4=(cT4*sin(PI/Th4))+(cRH4*cos(PI/Th4))

Tn=Tr4+h4;RHn=RHr4+k4

RH4max=b4*sqrt(1-((Tn-h4)/a4)^2)+k4
```

```
RH4min=-(b4*sqrt(1-((Tn-h4)/a4)^2))+k4

if((RHn<=RH4max)&&(RHn>=RH4min)){M=4}
else{
############################################################
cT5=T-h5;cRH5=RH-k5

Th5=3
Tr5=(cT5*cos(PI/Th5))-(cRH5*sin(PI/Th5))

RHr5=(cT5*sin(PI/Th5))+(cRH5*cos(PI/Th5))

Tn=Tr5+h5;RHn=RHr5+k5

RH5max=b5*sqrt(1-((Tn-h5)/a5)^2)+k5
RH5min=-(b5*sqrt(1-((Tn-h5)/a5)^2))+k5

if((RHn<=RH5max)&&(RHn>=RH5min)){M=5}
else{
############################################################
cT6=T-h6;cRH6=RH-k6

Th6=2.90
Tr6=(cT6*cos(PI/Th6))-(cRH6*sin(PI/Th6))

RHr6=(cT6*sin(PI/Th6))+(cRH6*cos(PI/Th6))

Tn=Tr6+h6;RHn=RHr6+k6

RH6max=b6*sqrt(1-((Tn-h6)/a6)^2)+k6
RH6min=-(b6*sqrt(1-((Tn-h6)/a6)^2))+k6
```

```
if((RHn<=RH6max)&&(RHn>=RH6min)){M=6}
else{
###########
}}}}}}
print $0, M;M=7
}
```

Second program

```
BEGIN{Ms1=0}
{
if($6==1){r=1;S1++;S2++;S3++;S4++;S5++;S6++}
if($6==2){r=2;S2++;S3++;S4++;S5++;S6++;S1=0}
if($6==3){r=4;S3++;S4++;S5++;S6++;S1=0;S2=0}
if($6==4){r=8;S4++;S5++;S6++;S1=0;S2=0;S3=0}
if($6==5){r=16;S5++;S6++;S1=0;S2=0;S3=0;S4=0}
if($6==6){r=32;S6++;S1=0;S2=0;S3=0;S4=0;S5=0}
if($6==7){r="NA";S1=S2=S3=S4=S5=S6=0;M=0}

if(S1>=1){M=1;Ms++}
if(S2>=2){M=1;Ms++}
if(S3>=4){M=1;Ms++}
if(S4>=8){M=1;Ms++}
if(S5>=16){M=1;Ms++}
if(S6>=32){M=1;Ms++}

if(M==1){Ms1++
#print $0,S1,S2,S3,S4,S5,S6,"M",M,Ms1
}

#print $0,S1,S2,S3,S4,S5,S6,"M",M
print $0,"M",M,Ms1
```

```
M=0
}
END{print "***TOTAL***",Ms1}
```

Degree days

```
BEGIN{Y1=1961;Tb=15.0}
{
A=$2
if(A==01){A=1};if(A==02){A=2};if(A==03){A=3};if(A==04){A=4};if(A==05){A=5};if(A==06){A=6};if(A==07){A=7};if(A==08){A=8};if(A==09){A=9}

T[A]=$4;Tb=15.0
if(T[A]<=Tb){Tb=T[A]}
DD[A]=T[A]-Tb
GDD[A]+=DD[A]
}
END{
for(A=01;A<=12;A++){
print GDD[A]/30}
}
```

Working with multiple large files

Typically there are 100 files of outdoor data for each time period and each location. These must all be transferred indoors, and then investigated for damage, along with other steps. To run the AWK programs individually 100 times would take a long time, fortunately it is possible to automate this process.

In command prompt the following instructions instruct the AWK program to run for every file with the ending .csv, this can of course be changed.

The command is:

For %X in (*.csv) do awk95 –f a.awk %X>a%X

%X is the variable within the command. This is the filename.

a.awk is the AWK program executed, on every file ending in .csv

here the output creates a new file (it is possible to append to the same file using >>), with the name a%X. Care must be taken to create a filename that comes before the set of 100 files, otherwise the command will continue to run to infinity with the newly created files. Holding control and C stops any command from running if this occurs.

Where there is a large amount of information, such as when assessing data seasonally it is possible to pipe the output of commands to another routine. With the seasonal data there is a significant amount of data, but there is only a small amount required at the end, such as the three values representing the interquartile range. Piping the whole data set to a sort routine built into command prompt and back to a file that prints the three values saves a significant amount of time. It is possible to do this for every day and append it into a new file, to do this manually would require 36500 individual commands to be inputted, and this is with the raw data that has not be transferred indoors. It would take a very long time.

APPENDIX F

PUBLICATIONS

Two publications directly resulting from this work have been published to date, they are included here