On 18th and 19th Century Sacristy Furniture in the Maltese Islands: Materials, Techniques, Preservation

Volume 2

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A dissertation submitted in partial fulfilment of the requirements of

M. Cons.

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Volume II

Appendices

Appendix 1 – Methodology of wood identification

Introduction

Aim: To identify the genus and, possibly, the species of the different types of wood used in local sacristy furniture

Introduction

Samples were taken directly from furniture but, in some cases, they were taken from detached elements like, for example, pieces of mouldings that came off and were stored. During all the analyses, only temporary slides were made.

Equipment and Materials

The list below shows the equipment and materials used in the process of wood identification:

Sample taking	scalpel, razor blade
Mounting	glass slide, cover slip, deionised water
Analysis	binocular light microscope (Olympus BX50)

Methodology

1 Wood Anatomy

A macroscopic observation was carried out prior to the microscopic investigation. Wood was initially inspected in order to choose the best location for sampling. Care was taken not to take samples from exposed areas and, therefore, whenever possible, these were collected from the less prominent areas like, for example, the interior of a door, or from inside a cupboard.

2 Sampling

2.1 Samples were collected in the form of a small splinter, and perfect transverse, tangential and radial sections were taken in the laboratory. Green tree branches of six types of indigenous trees were collected; these were about 2.5 cm in diameter and about 2.5 cm long.

2.2 The areas to be sectioned were first wetted with deionised water. A razor blade was then used to take thin shavings of the three representative sections.

2.3 Samples were placed on glass slides which already had some drops of deionised water on them.

2.4 Subsequently, cover slips were immediately put onto the wet samples.

3 Microscopic investigation

3.1 The mounted samples were viewed under the light microscope at different magnifications: mainly at 100x, 200x and 400x. Certain cell elements like, for example, cross field pits, required the highest magnification possible (1000x).

3.2 All observed gymnosperm characteristics were compared with published data (Schweingruber, Fritz Heins, *Anatomy of European woods*; Bern, Stuttgart: Paul Haupt Erne and Stuttgart Publishers, 1990) until the genera was identified. Furthermore a Microsoft Excel computation, designed by the author, was also regularly used. Angiosperm mounted samples were matched with a computer program by the name of *Intkey*.

3.3 The general characteristics that were observed and studied under the light microscope for gymnosperm and angiosperm sections were:

Transverse section – Gymnosperm	
Main Characteristics	- presence of tracheids
	- earlywood and latewood tracheid cell wall thickness
	- resin canals (present or absent)
	- resin canals (large or small)
Other Characteristics	- growth ring boundaries (distinct or indistinct)
	- early-latewood transition (abrupt or gradual)

Tangential section - Gymnosperm	
Main Characteristics	- resin canals (present or absent) - longitudinal parenchyma (present or absent) - spiral thickening in tracheids (present or absent)
Other characteristics	- height of rays (minimum, maximum and average number of cells)

Radial section - Gymnosperm	
Main Characteristics	- ray tracheids (present or absent) - ray tracheid cell wall (smooth or dentate) - cross field pits in earlywood (taxodoid, pinoid, piceoid, cupressoid or fenestriform) - cross field pits in late wood (Taxodoid, pinoid, piceoid, cupressoid or fenestriform) - number of pits per crossfield (1,2,3,4,5 or 6) - ray parenchyma transverse wall (nodular or smooth) - ray parenchyma tangential wall (dentate or smooth) - crystals in rays (present or absent) - longitudinal parenchyma (present or absent) - longitudinal parenchyma end wall (smooth or nodular) - spiral thickening in tracheids (present or absent) - bordered pits (uni-biseriate)

Transverse section [A] – Angiosperm	
Main Characteristics	- presence of vessels (pores) fibres and fibre tracheids - vessel layout (ring, diffuse or semi-diffuse porous) - vessel layout (single, multiple or in clusters) - vessel size (large, medium or small) - vessel outline (round or angular) - pore distribution (regular or irregular)

	-	axial parenchyma (marginal, apotracheal or paratracheal)
Other Characteristics	-	presence of tyloses in vessels
	-	growth ring boundaries (distinct or indistinct)

Tangential section [T] – Angiosperm		
Main Characteristics	-	parenchyma cells (uni-to-biseriate, uni- and multiseriate, uni-to 5 seriate, bi-to 3 seriate, 3 to 5 seriate or 6+ seriate)
	-	spiral thickening (present or absent)
Other Characteristics	-	parenchyma cells (round, oval or irregular)
	-	longitudinal parenchyma

Radial section [R] – Angiosperm		
Main Characteristics	-	parenchyma rays (heterogeneous, homogeneous or upright)
	-	vessel perforations (simple or scalariform)
	-	intervessel pits (opposite or alternate)
	-	spiral thickening (present or absent)
Other Characteristics	-	longitudinal parenchyma

3.4 Observed characteristics of two gymnosperm samples

Family	*Pinaceae*
Genus	*Pinus*
Species	probably *sylvestris*
English name	scots pine
Characteristics	**Section**

Early-latewood transition	gradual	transverse
Resin canals	present	transverse/tangential
Resin canals -Epithelial cells	thin	transverse
Ray tracheids	present	radial
Walls or ray tracheids	dentate	radial
Crossfield pits	fenestriform	radial
Longitudinal parenchyma	absent	tangential/radial
Spiral thickening	absent	tangential/radial
Bordered pits	unicellular	radial
Crystals in Ray parenchyma	not observed	radial

Family	*Pinaceae*	
Genus	*Abies*	
Species	*sp.*	
English name	Fir	
Characteristics		**Section**
Early-latewood transition	gradual	transverse
Resin canals	absent	transverse/tangential
Resin canals -Epithelial cells	absent	transverse
Ray tracheids	absent	radial
Walls or ray tracheids	absent	radial
Crossfield pits	taxodoid	radial
Longitudinal parenchyma	absent	tangential/radial
Spiral thickening	absent	tangential/radial
Bordered pits	unicellular	radial
Crystals in Ray parenchyma	not observed	radial

3.5 Observed characteristics of two angiosperm samples

Family	*Fagaceae*	
Genus	*Castanea*	
Species	*Sativa* Mill.	
English name	chestnut	
Characteristics		**Section**
Vessels	ring porous	transverse
Layout	solitary in earlywood	transverse
Perforation plates	simple	radial
Intervessel pits	alternate	radial
Axial parenchyma	apotracheal and paratracheal	transverse
Growth ring boundaries	distinct	transverse
Ray parenchyma	uniseriate	tangential
Type	homocellular	radial
Helical thickening	absent	tangential/radial

Family	*Tiliaceae*	
Genus	*Tilia*	
Species	*sp.*	
English name	lime	
Characteristics		**Section**
Vessels	diffuse porous	transverse
Layout	multiples (2-3) radial rows and in clusters. Vessel outline angular	transverse

Perforation plates	simple	radial
Intervessel pits	alternate	radial
Axial parenchyma	marginal	transverse
Growth ring boundaries	distinct	transverse
Ray parenchyma	multiseriate (1-6)	tangential
Type	homocellular	radial
Helical thickening	present	tangential/radial

Wood identification results

Sample	Location		Date	Sample	Latin name	English Name
1	Malta	Attard	18th	platform	*Picea sp. or Larix decidua*	Spruce or Larch
2	Malta	Attard	18th	door	*Picea sp. or Larix decidua*	Spruce or Larch
3	Malta	Attard	18th	drawer construction	*Picea sp.*	Spruce
4	Malta	Balzan (left)	19th ?	door	*Picea sp.*	Spruce
5	Malta	Balzan (left)	19th ?	plinth	*Picea sp.*	Spruce
6	Malta	Balzan (right)	19th	plinth	*Larix decidua*	Larch
7	Malta	Balzan (right)	19th	door	*Larix decidua*	Larch
8	Malta	Birkirkara - Ħerba	18th	bench – cupboard	*Picea sp.*	Spruce
9	Malta	Birkirkara - Ħerba	18th	door	*Picea sp.*	Spruce
10	Malta	Birkirkara - Ħerba	18th	drawer construction	*Picea sp.*	Spruce
11	Malta	Birkirkara - St Helen	18th	cornice	*Picea sp.*	Spruce
12	Malta	Birkirkara - St Helen	18th	door	*Picea sp. or Larix decidua*	Spruce or Larch
13	Malta	Birkirkara - St Helen	18th	drawer construction	*Picea sp.*	Spruce
14	Malta	Birkirkara - St Helen	18th	carcase	*Picea sp.*	Spruce
15	Malta	Birkirkara - St Helen	18th	door	*Castanea sativa (Miller)*	Chestnut
16	Malta	Birkirkara - St Helen	18th	platform	*Picea sp.*	Spruce
17	Malta	Birkirkara - St Helen	18th	drawer construction	*Picea sp.*	Spruce
18	Malta	Birkirkara - St Helen	18th	drawer construction	*Picea sp.*	Spruce
19	Malta	Birkirkara - St Helen	18th	carcase	*Abies sp.*	Fir
20	Malta	Birkirkara - St Helen (A)	19th	carcase	*Picea sp.*	Spruce
21	Malta	Birkirkara - St Helen (B)	19th	door	*Picea sp.*	Spruce
22	Malta	Birkirkara - St Helen (intermediate room)	19th	carcase	*Picea sp.*	Spruce

23	Malta	Birkirkara - St Helen (similar to interior doors)	19th	moulding	*Larix decidua*	Larch
24	Malta	Birkirkara - St Helen (similar ti interior doors)	19th	door	*Larix decidua*	Larch
25	Malta	Cospicua	18th	door	*Pinus sp. (sylvestris?)*	Pine (Scots?)
26	Malta	Ghaxaq	18th ?	moulding	*Picea sp.*	Spruce
27	Malta	Lija	19th	shelve	*Picea sp.*	Spruce
28	Malta	Lija	19th	door	*Picea sp.*	Spruce
29	Malta	Mdina	18th ?	door	*Picea sp.*	Spruce
30	Malta	Naxxar	18th	door	*Larix decidua*	Larch
31	Malta	Naxxar	18th	moulding	*Larix decidua*	Larch
32	Malta	Naxxar	18th	carcase	*Larix decidua*	Larch
33	Malta	Rabat - St Publius	18th	carcase	*Picea sp.*	Spruce
34	Malta	Rabat - St Publius	18th	drawer construction	*Picea sp.*	Spruce
35	Malta	Rabat - St Publius	18th	back	*Picea sp.*	Spruce
36	Malta	Rabat - St Publius	18th	shelve	*Picea sp.*	Spruce
37	Malta	Rabat - St Publius	18th	platform	*Picea sp.*	Spruce
38	Malta	Rabat - St Publius	18th	drawer construction	*Picea sp.*	Spruce
39	Malta	Rabat - St Publius	18th	door	*Picea sp.*	Spruce
40	Malta	Rabat - St Publius	18th	platform	*Picea sp.*	Spruce
41	Malta	Senglea - Parish Church	18th	cupboard top	*Larix decidua*	Larch
42	Malta	Senglea - Parish Church	18th	door	*Larix decidua*	Larch
43	Malta	Senglea - Parish Church	18th	moulding	*Larix decidua*	Larch
44	Malta	Senglea - St Philip	19th	drawer front	*Picea sp.*	Spruce
45	Malta	Senglea - St Philip	19th	door	*Larix decidua*	Larch

46	Malta	Senglea - St Philip	19th	carcase	*Larix decidua*	Larch
47	Malta	Senglea - St Philip	18th	moulding	*Picea sp. or Larix decidua*	Spruce or Larch
48	Malta	Siġġiewi	18th ?	carcase	*Pseudotsuga menziesii*	Douglas fir
49	Malta	Siġġiewi	18th ?	drawer construction	*Picea sp.*	Spruce
50	Malta	Tarxien left	?	moulding	*Picea sp.*	Spruce
51	Malta	Tarxien right	18th	door	*Picea sp. or Larix decidua*	Spruce or Larch
52	Malta	Valletta - St Dominic	19th	door	*Larix decidua*	Larch
53	Malta	Valletta - St Dominic	19th	cupboard top	*Larix decidua*	Larch
54	Malta	Valletta - St Dominic	19th	sculptural element	*Larix decidua*	Larch
55	Malta	Valletta - St John	18th	sculptural element	*Pinus sp. (sylvestris?)*	Pine (Scots?)
56	Malta	Valletta - St John	18th	drawer construction	*Picea sp.*	Spruce
57	Malta	Valletta - St John	18th	platform	*Picea sp. or Larix decidua*	Spruce or Larch
58	Malta	Valletta - St John	18th	moulding	*Larix decidua*	Larch
59	Malta	Valletta - St John	18th	cupboard top	*Larix decidua*	Larch
60	Malta	Valletta - St John	18th	drawer construction	*Picea sp. or Larix decidua*	Spruce or Larch
61	Malta	Valletta - St John	18th	drawer front	*Picea sp.*	Spruce
62	Malta	Valletta - St John	18th	carcase	*Larix decidua*	Larch
63	Malta	Valletta - St Paul	18th	sculptural element	*Tilia sp.*	Lime
64	Malta	Valletta - St Paul	18th	moulding	*Pseudotsuga menziesii*	Douglas fir
65	Malta	Valletta - St Paul	18th	moulding	*Larix decidua*	Larch
66	Malta	Valletta - St Paul	18th	door	*Larix decidua*	Larch
67	Malta	Żebbuġ - St Philip	18th	shelve	*Abies sp.*	Fir
68	Malta	Żebbuġ - St Philip	18th	platform	*Larix decidua*	Larch

69	Malta	Żebbuġ - St Philip	18th	bench – cupboard	*Larix decidua*	Larch
70	Malta	Żebbuġ - St Philip	18th	door	*Pinus sp. (sylvestris?)*	Pine (Scots?)
71	Malta	Żebbuġ - St Philip	18th	carcase	*Picea sp.*	Spruce
72	Malta	Żebbuġ - St Philip	18th	door	*Larix decidua*	Larch
73	Malta	Żebbuġ - St Philip	18th	bench – cupboard	*Larix decidua*	Larch
74	Malta	Żebbuġ - St Philip	18th	shelve	*Picea sp.*	Spruce
75	Malta	Żebbuġ - St Philip	18th	sculptural element	*Pinus sp. (sylvestris?)*	Pine (Scots?)
76	Malta	Żebbuġ - St Philip	18th	bench – lid	*Larix decidua*	Larch
77	Malta	Żebbuġ - St Philip	18th	door interior	*Picea sp.*	Spruce
78	Malta	Żebbuġ - St Philip	18th	door interior	*Picea sp.*	Spruce
79	Malta	Żejtun	18th	carcase	*Larix decidua*	Larch
80	Malta	Żejtun	18th	moulding	*Larix decidua*	Larch
81	Malta	Żejtun	18th	moulding	*Pseudotsuga menziesii*	Douglas fir
82	Malta	Żurrieq	18th	door	*Larix decidua*	Larch
83	Gozo	Rabat- Capuchins	18th ?	carcase	*Castanea sativa (Miller)*	Chestnut
84	Gozo	Citadel - Victoria	18th	moulding	*Picea sp.*	Spruce
85	Gozo	Citadel - Victoria	18th	moulding	*Acer sp. or Prunus sp.*	Maple or Cherry
86	Gozo	Citadel - Victoria	18th	platform	*Larix decidua*	Larch
87	Gozo	Citadel - Victoria	18th	door	*Larix decidua*	Larch
88	Gozo	Citadel - Victoria	18th	bench – cupboard	*Larix decidua*	Larch
89	Gozo	Citadel - Victoria	18th	sculptural element	*Acer sp. or Prunus sp.*	Maple or Cherry
90	Gozo	Rabat - Franciscans	18th	drawer construction	*Picea sp.*	Spruce
91	Gozo	Rabat - Franciscans	18th	door	*Larix decidua*	Larch

92	Gozo	Rabat - Franciscans	18th	door	*Larix decidua*	Larch
93	Gozo	Għarb	18th	door	*Larix decidua*	Larch
94	Gozo	Għarb	18th	carcase	*Larix decidua*	Larch
95	Gozo	Sannat	18th	moulding	*Picea sp.*	Spruce
96	Gozo	Sannat	18th	door	*Picea sp.*	Spruce
97	Gozo	Sannat	19th	platform	*Picea sp. or Larix decidua*	Spruce or Larch
98	Gozo	Sannat	19th	carcase	*Picea sp. or Larix decidua*	Spruce or Larch
99	Gozo	Sannat	19th	door	*Picea sp. or Larix decidua*	Spruce or Larch
100	Gozo	Xagħara	18th ?	carcase	*Picea sp.*	Spruce
101	Gozo	Xagħara	18th ?	door	*Picea sp.*	Spruce
102	Gozo	Xewkija	18th ?	chair	*Juglans sp.*	Walnut
103	Gozo	Xewkija	18th ?	chair	*Juglans sp.*	Walnut
104	Gozo	Xewkija	19th ?	carcase	*Picea sp. or Larix decidua*	Spruce or Larch
105	Maltese indigenous trees				*Pinus halepensis*	Jerusalem pine
106	Maltese indigenous trees				*Tetraclinis articulata*	Sandarac
107	Maltese indigenous trees				*Fraxinus angustifolia*	Ash
108	Maltese indigenous trees				*Quercus ilex*	Holly/ Holm oak
109	Maltese indigenous trees				*Populus alba*	Poplar
110	Maltese indigenous trees				*Cupressus sempervirens*	Juniper/Cypress

Table 1 Locations sampled and ensuing results

Wood identification proforma sheets – St Publius' sacristy, Rabat

Diagnostic Science Laboratories
MALTA CENTRE for RESTORATION
Incorporating the Institute for Conservation and Restoration Studies
Bighi, Kalkara CSP12 - Malta Tel: (+356) 21807675/ 6, Fax: (+356) 21674457

WOOD IDENTIFICATION

ST. PUBLIUS' SACRISTY, RABAT

- PROFORMA SHEET *W1 – MACROSCOPIC AND OTHER PHYSICAL INVESTIGATIONS*
- PROFORMA SHEET *W2 – SAMPLING*
- PROFORMA SHEET *W3 – MICROSCOPIC INVESTIGATIONS*
- *RESULT SHEET*

St Publius sacristy, Rabat

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WOOD IDENTIFICATION

PROFORMA SHEET *W1*

MACROSCOPIC AND OTHER PHYSICAL INVESTIGATIONS

SAMPLING DATA

MCR SAMPLE ACCESSION NUMBERS	840 (carcase) 841 (drawer runner) 842 (back) 843 (shelve) 844 (platform B) 845 (drawer bottom) 846 (door) 847 (platform C)
DATE OF MACROSCOPIC EXAMINATION	26th April 2004
EXAMINED BY	Michael Formosa

GENERAL CHARACTERISTICS

The rear of the doors was not treated and this made macroscopic investigation easy. Other locations such as platforms, carcase, drawers and shelves showed the same macroscopic features. The wood is two-coloured having a pale yellow early wood against a red-brown late wood. It is quite soft and has a slight resinous smell. The lightest areas, which are not so pronounced, may indicate the presence of sapwood. It is clearly a gymnosperm (softwood) but microscopic investigations were needed to determine the family, genus and, in certain cases, sometimes the species of the wood used. Knots situated in pairs might suggest the presence of *Picea sp.* (spruce), even though sapwood is not usually visible in this type of wood.

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WOOD IDENTIFICATION

PROFORMA SHEETS *W2 - SAMPLING*

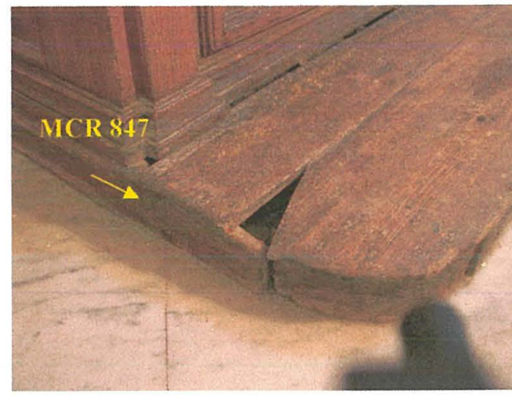
SAMPLING DATA

MCR SAMPLE ACCESSION NUMBERS	840 (carcase) 841 (drawer runner) 842 (back) 843 (shelve) 844 (platform B) 845 (drawer bottom) 846 (door) 847 (platform C)
DATE EXAMINED	26th April 2004
SAMPLED BY	Michael Formosa

OBJECT REFERENCE DATA

OBJECT TYPE	Sacristy furniture
DIMENSIONS	Room is approximately 6.8m x 6.6m
CHRONOLOGY	Early 18th century
CURRENT LOCATION	St. Publius Church, Rabat
GENERAL DESCRIPTION OF THE CONDITION OF THE OBJECT	The furniture inside the sacristy is in a stable condition. It suffers from poor restoration treatments, physical abrasions and minor insect infestations.
LOCATION AND DESCRIPTION OF AREA SAMPLED	Samples were taken from the inside of the cupboards for the carcase and shelving. Samples for the door, drawer and platform were taken from areas which are not prominent and not noticeable on viewing the sacristy furniture from the outside.

PHOTOGRAPHS OF SAMPLED AREAS



REASON FOR SAMPLING	Identification of Wood
DIRECTION OF SAMPLE TAKING	Transverse, tangential and radial
SAMPLE TYPE	splinter

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WOOD IDENTIFICATION

PROFORMA SHEETS *W3*

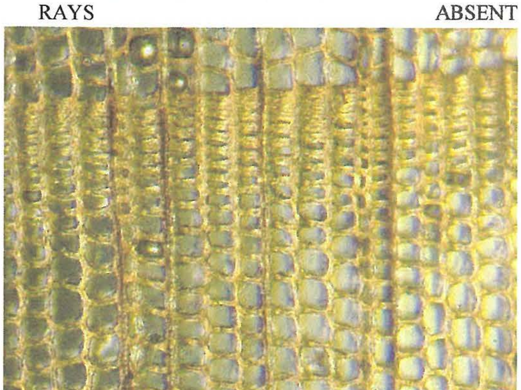
MICROSCOPIC INVESTIGATIONS

SAMPLING DATA

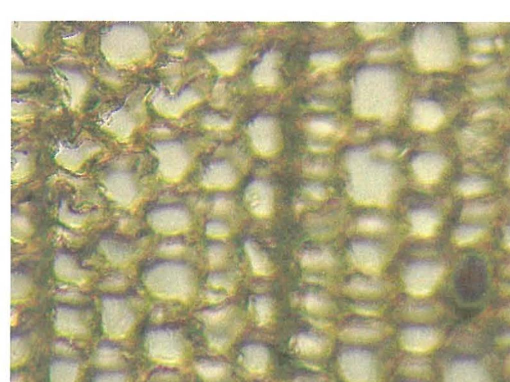
MCR SAMPLE ACCESSION NUMBERS	840 (carcase) 841 (drawer runner) 842 (back) 843 (shelve) 844 (platform B) 845 (drawer bottom) 846 (door) 847 (platform C)
DATE OF SAMPLE EXAMINATION	30th August 2004
SAMPLED BY	Michael Formosa

OBSERVATIONS – TRANSVERSE SECTIONS

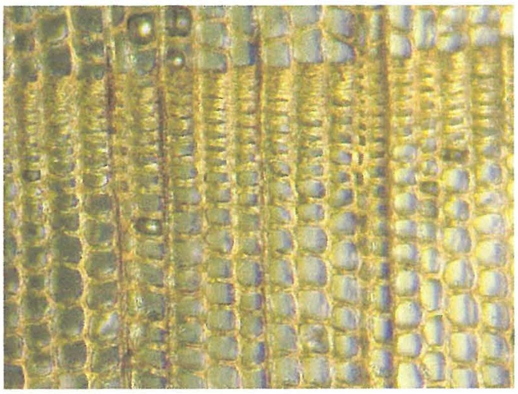
RESIN CANALS	PRESENT IN SOME SECTIONS
EARLY - / LATE WOOD TRANSITION	GRADUAL
LONGITUDINAL PARENCHYMA RAYS	ABSENT



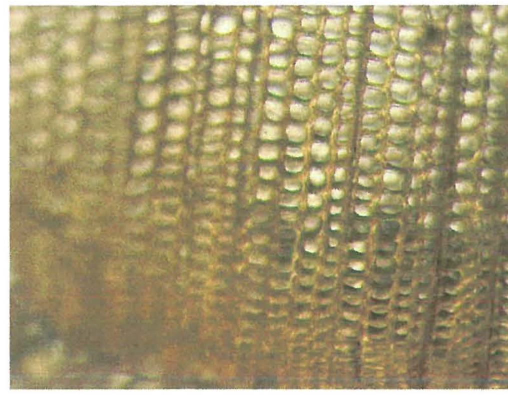
Sample 840 (200x)



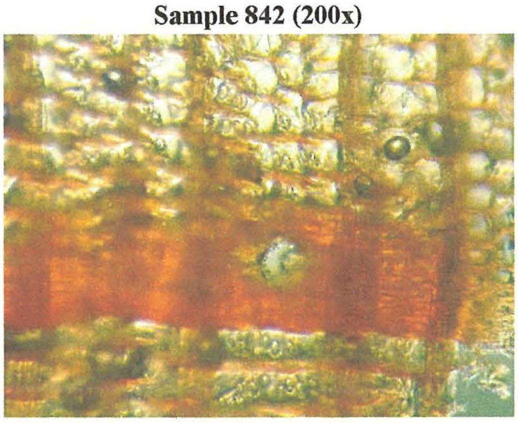
Sample 841 (400x)



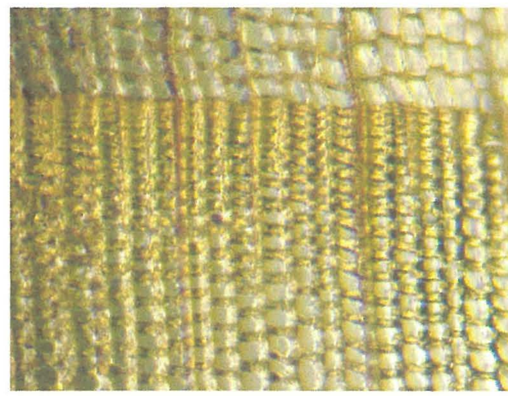
Sample 842 (200x)



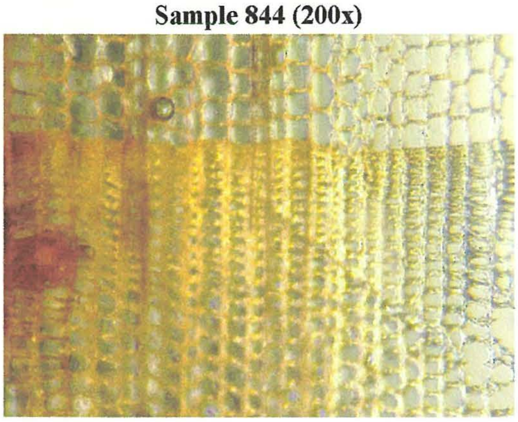
Sample 843 (200x)



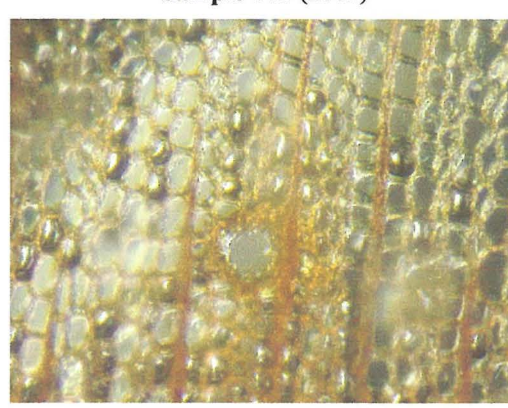
Sample 844 (200x)



Sample 845 (200x)



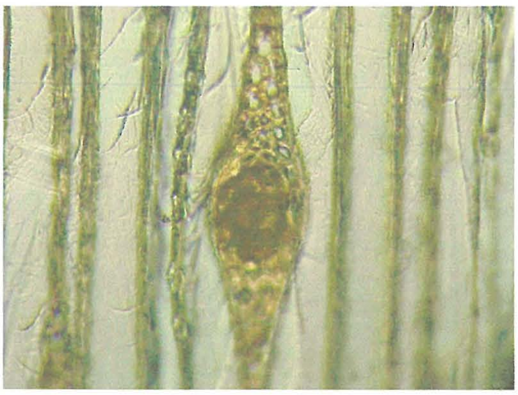
Sample 846 (200x)



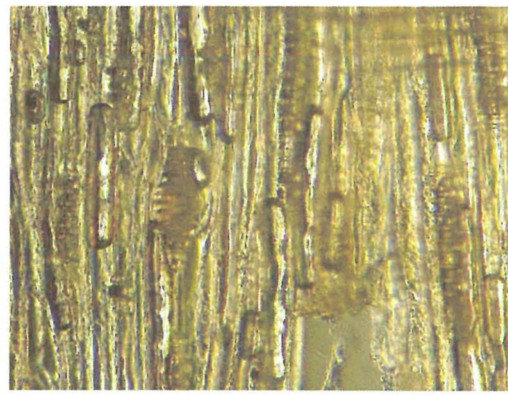
Sample 847 (200x)

OBSERVATIONS – RADIAL SECTIONS

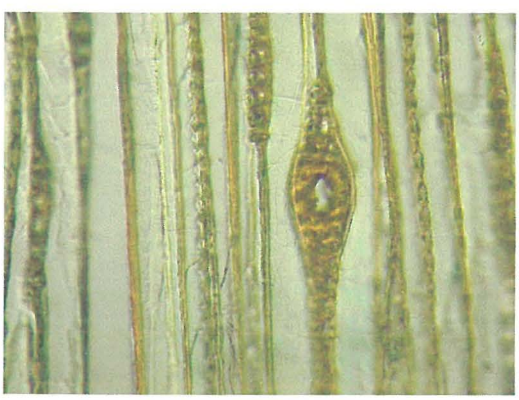
FUSIFORM RAYS	PRESENT
PARENCHYMA RAYS	UNISERIATE
SPIRAL THICKENING	ABSENT
AXIAL PARENCHYMA	ABSENT



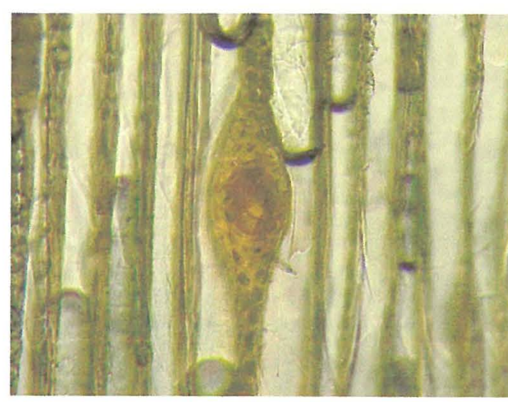
Sample 840 (200x)



Sample 841 (100x)



Sample 842 (200x)



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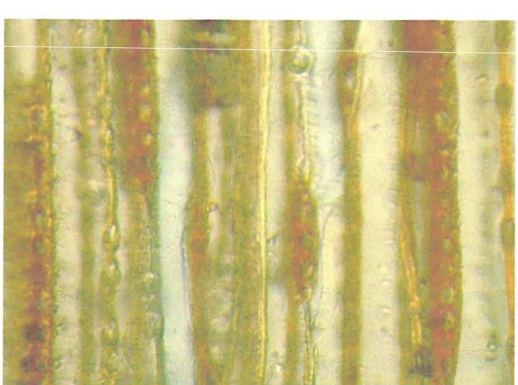

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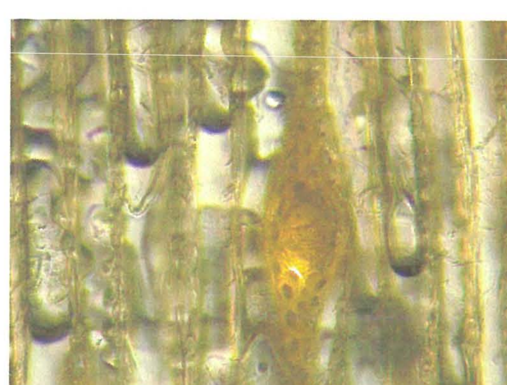

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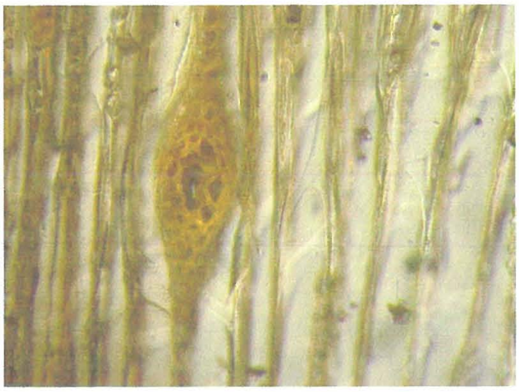

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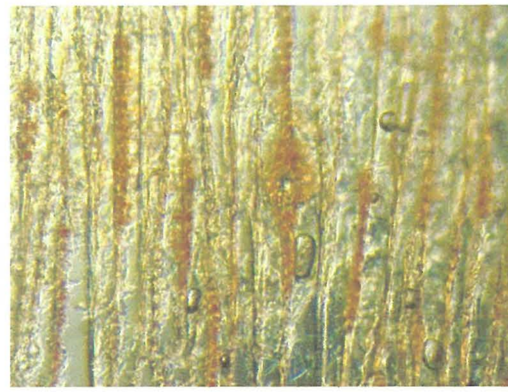
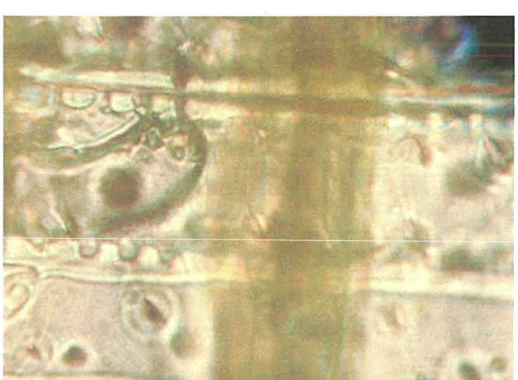


Sample 847 (100x)

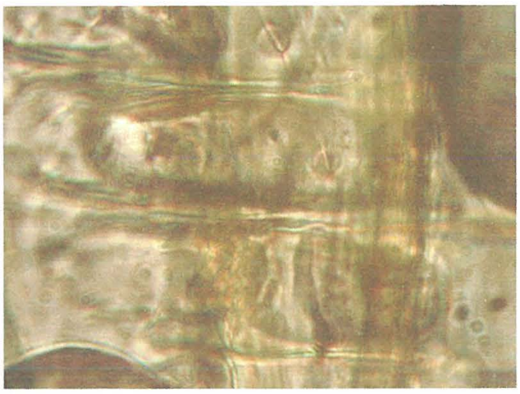
OBSERVATIONS – RADIAL SECTIONS

RAY TRACHEIDS	PRESENT
RAY TRACHEID CELL WALL	SMOOTH
AXIAL PARENCHYMA	ABSENT
CROSSFIELD PITS	PICEOID
LONGITUDINAL PARENCHYMA	ABSENT
SPIRATL THICKENING	ABSENT
BORDERED PITS	MOSTLY UNISERIATE



Sample 840 (1000x)

Sample 841 (1000x)



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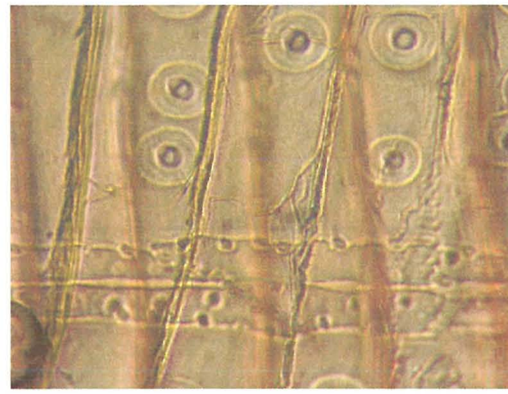
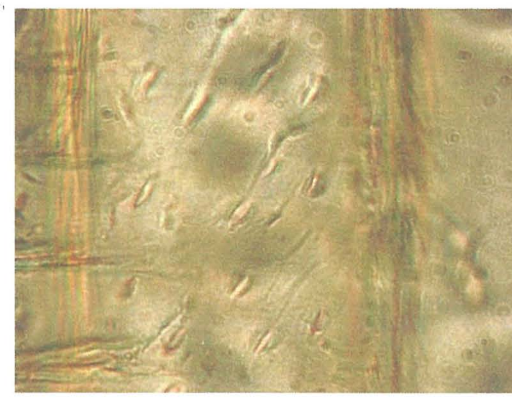


Sample 843 (1000x)

Sample 844 (1000x)



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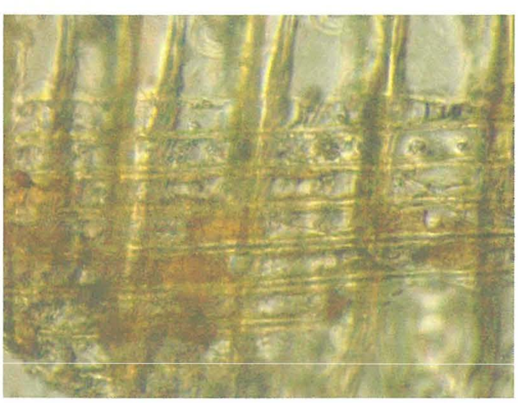

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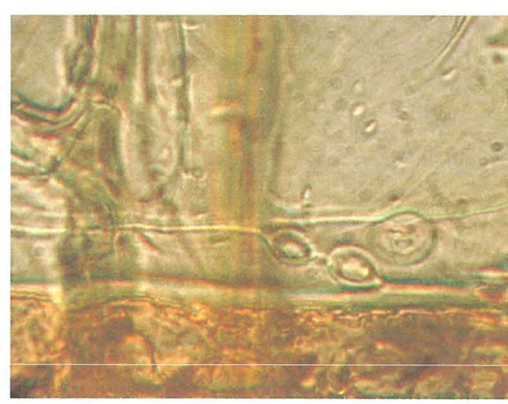

Sample 847 (1000x)

Diagnostic Science Laboratories
MALTA CENTRE for RESTORATION
Incorporating the Institute for Conservation and Restoration Studies

WOOD IDENTIFICATION

RESULT SHEET

ST. PUBLIUS CHURCH, RABAT – SACRISTY FURNITURE

Sample numbers

840 (carcase)
841 (drawer runner)
842 (back)
843 (shelve)
844 (platform B)
845 (drawer bottom)
846 (door)
847 (platform C)

The macroscopic and microscopic investigations indicated that the wood used for all the abovementioned samples is *Picea sp.* (spruce). The anatomical characteristics of spruce are very close to those of *Larix decidua* (larch). The light-coloured wood of the samples as well as the rare locations with biseriate bordered pits was enough to distinguish spruce from larch.

Taxonomy for spruce	
Class	*Gymnospermae*
Order	*Coniferales*
Family	*Pinaceae*
Genus	*Picea*
Species	*

* Species of the genera *Picea* are not anatomically distinguishable from each other.

Appendix 2 – Environmental monitoring

Environmental monitoring

Monitoring was carried out by using two HOBO H08-004-02 data loggers. These were placed in St Helen's Basilica's eighteenth century sacristy at Birkirkara, and the other one in St John's Conventual Church's eighteenth century sacristy, Valletta. In Birkirkara, the logger was placed on the cupboards by the side walls. In Valletta, it was placed on the cornice on top of the north-west cupboards. Both loggers recorded the ambient conditions (RH, T, light readings) of the room starting on the 24th and 19th August 2004 for St Helen's and St John's respectively. Monitoring was programmed to be carried out for one whole year but only data till June 2005 was considered in this study. The readings of RH and T were recorded every two hours (i.e., starting at midnight, 02:00, 04:00, 06:00, etc.).

During the period 24th till 30th June, the loggers were set to read light measurements as well. This time the loggers were placed on top of the west cupboard in Birkirkara and on top of the architectural decoration on top of the north-east wall in Valletta [Plate 1]. The results from the logger were in footcandle (lumens/ft^2) and calculations were made to convert into lux (lumen/m^2).

Plate 1 Location of data logger in the new sacristy of St John's Conventual Church, Valletta

Readings of the interior conditions were compared with the RH and T records of the exterior. The latter data were kindly provided by the Meteorological Office at Luqa. External data was recorded every minute and in GMT time; so it was necessary to select the appropriate hour corresponding to the interior readings. The Birkirkara weather station was located on the roof of the Birkirkara police station, which is in actual fact about 100 metres away from the church under study, while that for Valletta was stationed in Fort St Elmo which is about 1.2 km from St John's co-cathedral. The latter is also at shallower latitude than the co-cathedral and also surrounded by the sea. This condition was expected to reflect slight discrepancies with respect to ambient conditions present at St John's.[1]

All data was inserted into Microsoft Excel and, for each location, the following RH and T graphs were plotted:

- Bi-hourly readings month by month – August 2004 up to June 2005 [Figures 1 to 4]
- Mean daily readings for each month – August 2004 up to June 2005 [Figures 5 to 8]
- Mean bi-hourly readings for each month – August 2004 up to June 2005 [Figures 9 to 12]
- Mean monthly readings – August 2004 up to June 2005 [Figures 13 and 14]

In order to check the amount of air exchange in St John's sacristy, where the windows are opened regularly, the data loggers were set every five minutes for a period of twenty four hours. To get an accurate measure of the quantity of water present in the air the *g/m³* obtained from the data loggers were converted into *Kg/Kg* by using Excel worksheets. [Figures 15 to 18]

The collected data was also used to prepare and plot graphs for the mean monthly wood moisture content [Figure 19], the prediction of the *Anobium punctatum* larvae rate of development [Figures 20 to 27][2] as well as the mould activity [Figures 28 and

[1] Mr Saviour Porter, Chief Meteorological Officer, indicated that variations of RH can approximately vary by about 4% RH. Such changes are not so critical for the purpose of this study.
[2] The figures are in pairs since insect activity depends on both T and wood MC.

29] taking place during each month monitored. Figures 30 to 33 show the light measurement of both sacristies.

Relative Humidity and Temperature charts

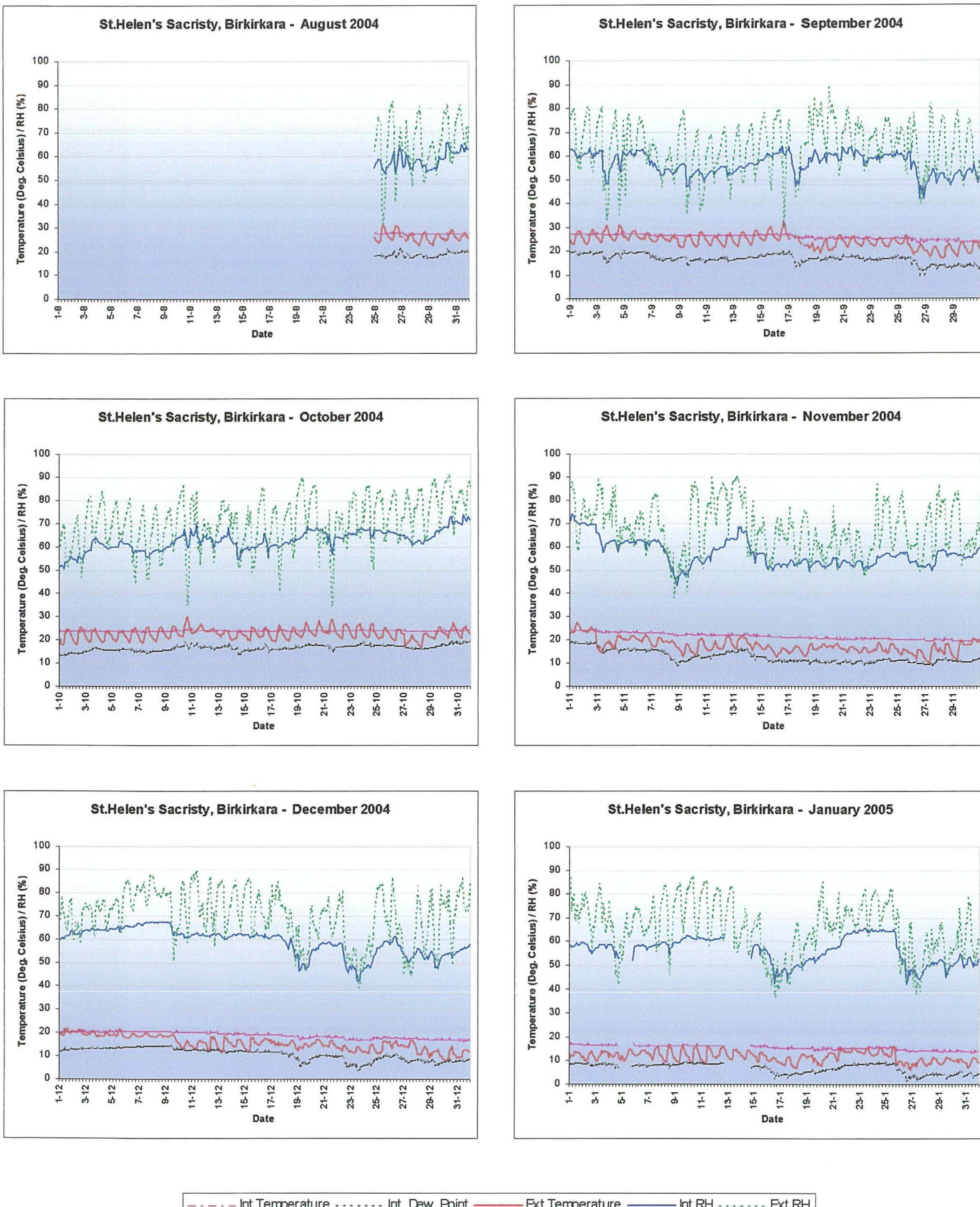

Figure 1 Bi-hourly relative humidity and temperature – Birkirkara, August 2004 - January 2005*

****Note: Internal data from 12-01-05, 18:00 to 14-01-05, 16:00 were not recorded due to technical problems with the recording instrument.***

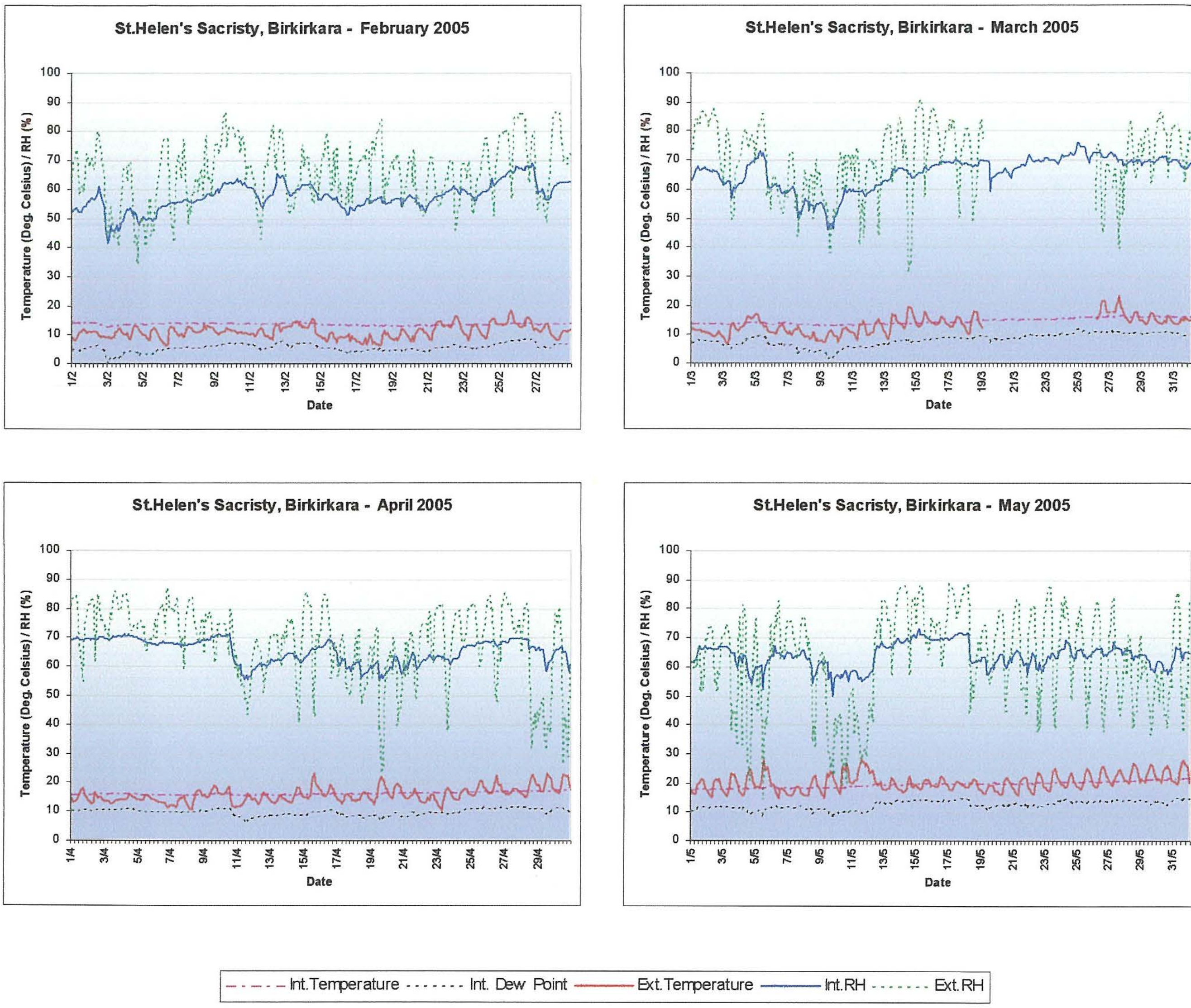

Figure 2 Bi-hourly relative humidity and temperature – Birkirkara, February 2005 - May 2005*

Note: External data from 19-03-05, 02:00 to 26-03-05, 00:00 were not recorded due to technical problems with the recording instrument at the Birkirkara station.

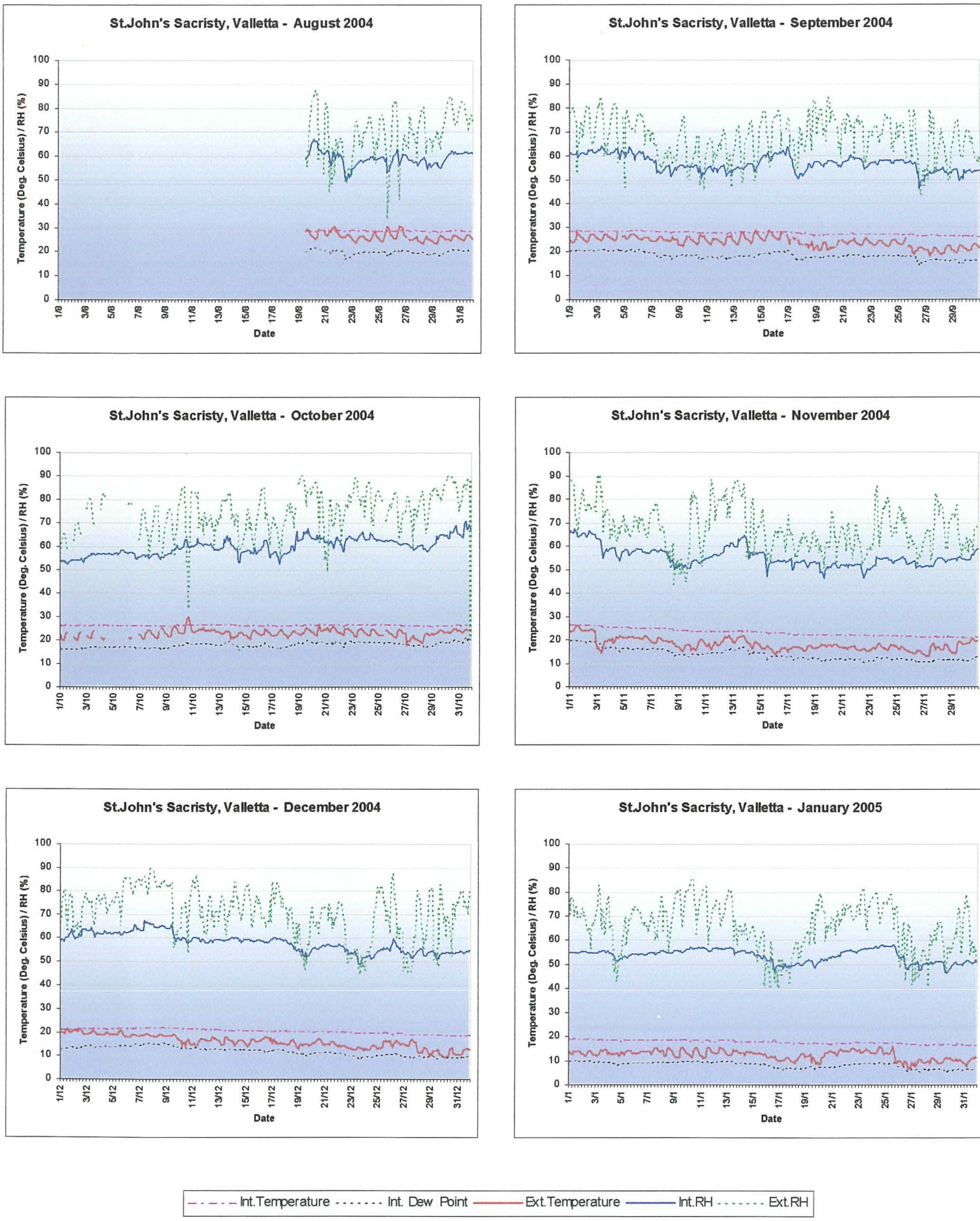

Figure 3 Bi-hourly relative humidity and temperature – Valletta, August 2004 - January 2005*

****Note: Internal data from 01-10-04, 14:00 to 06-10-05, 20:00 were interrupted due to technical problems with the recording instrument at St Elmo, Valletta station.***

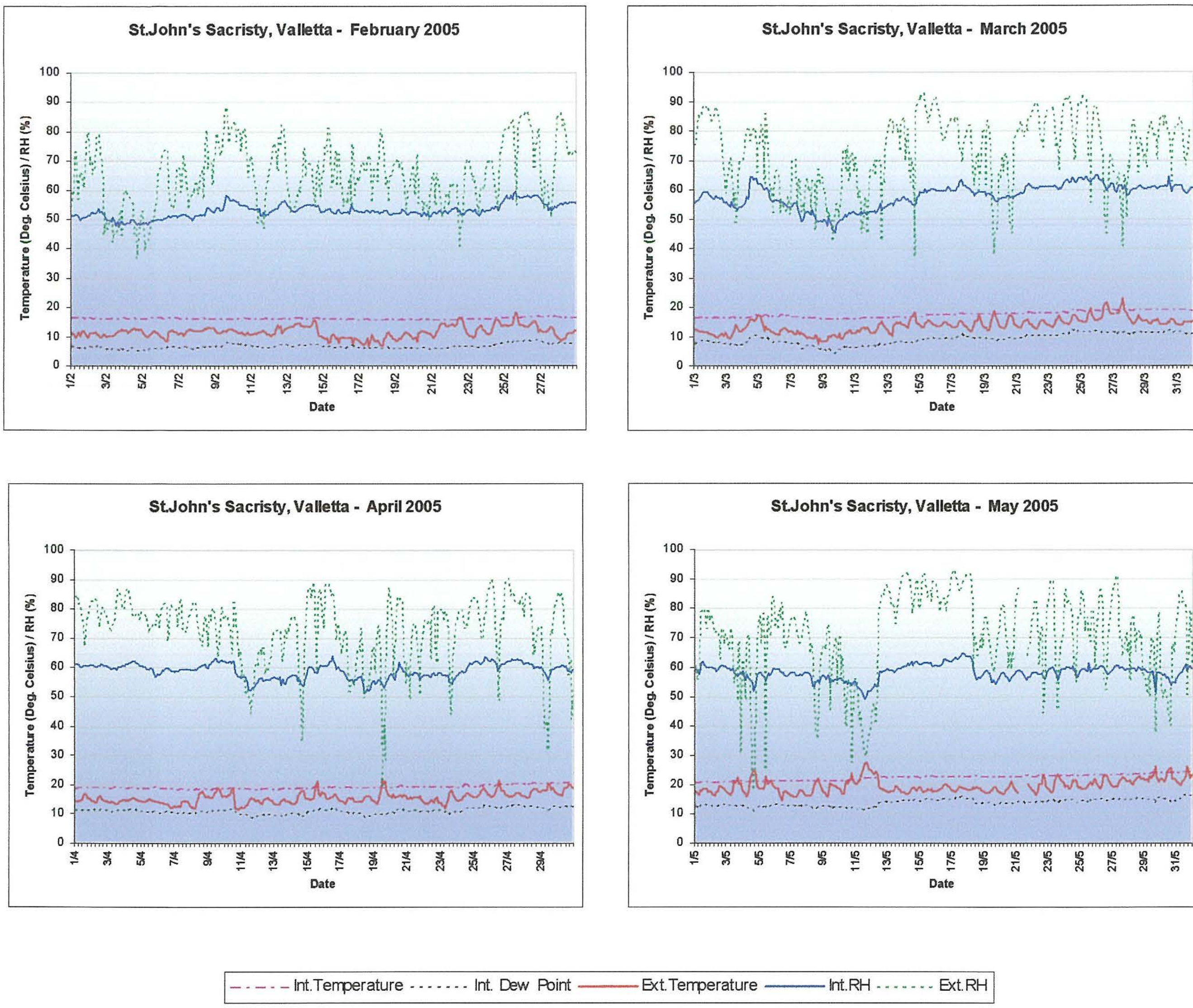

Figure 4 Bi-hourly relative humidity and temperature – Valletta, February 2005 - May 2005

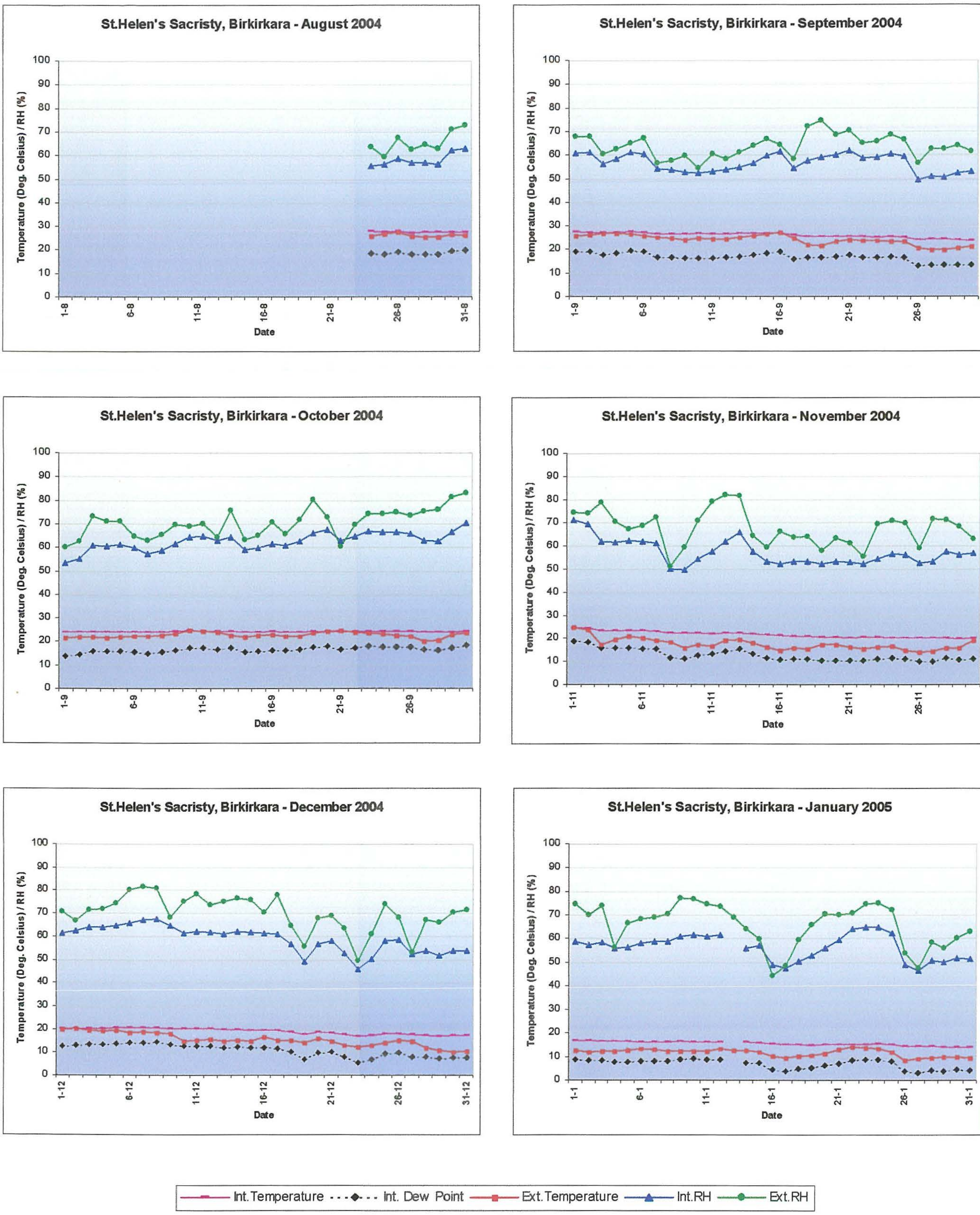

Figure 5 Mean daily relative humidity and temperature – Birkirkara, August 2004 - January 2005*

****Note: Internal data on 13-01-05 was interrupted due to technical problems with the recording instrument.***

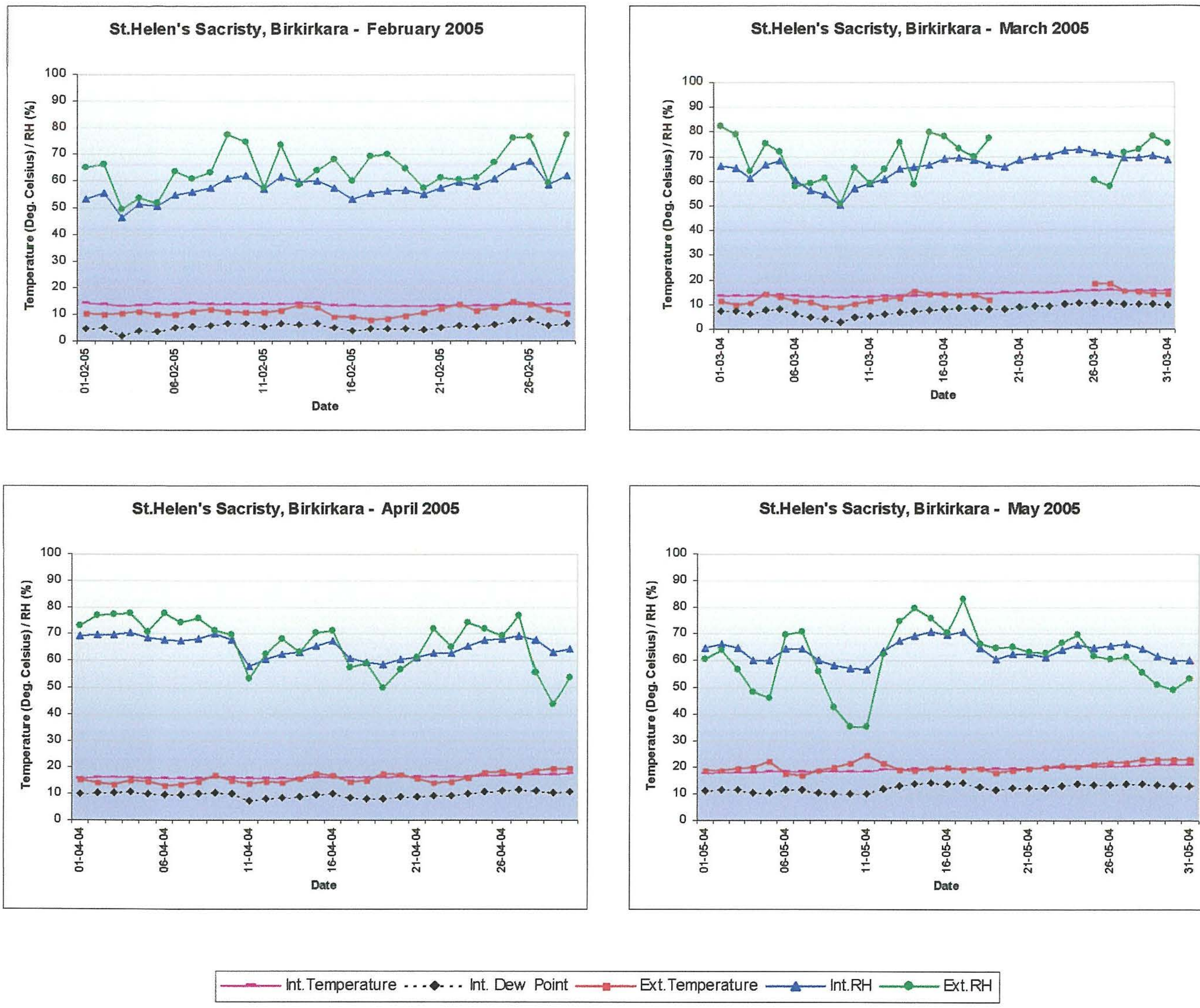

Figure 6 Mean daily relative humidity and temperature – Birkirkara, February 2005 - May 2005*

****Note: External data from 20-03-05 to 25-03-05 was interrupted due to technical problems with the recording instrument at the Birkirkara station.***

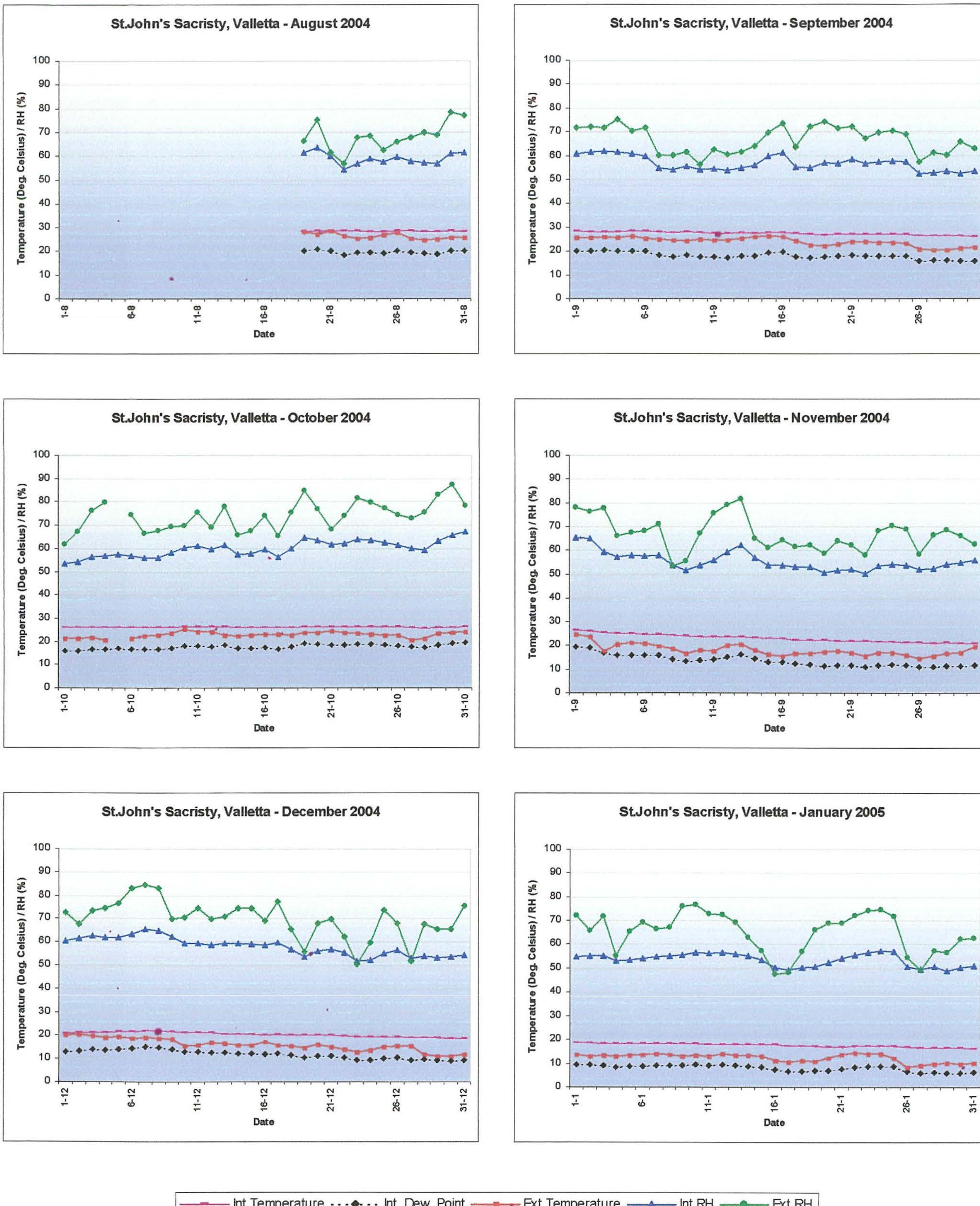

Figure 7 Mean daily relative humidity and temperature – Valletta, August 2004 - January 2005*

****Note: Internal data on 05-10-04 was interrupted due to technical problems with the recording instrument at St Elmo, Valletta station.***

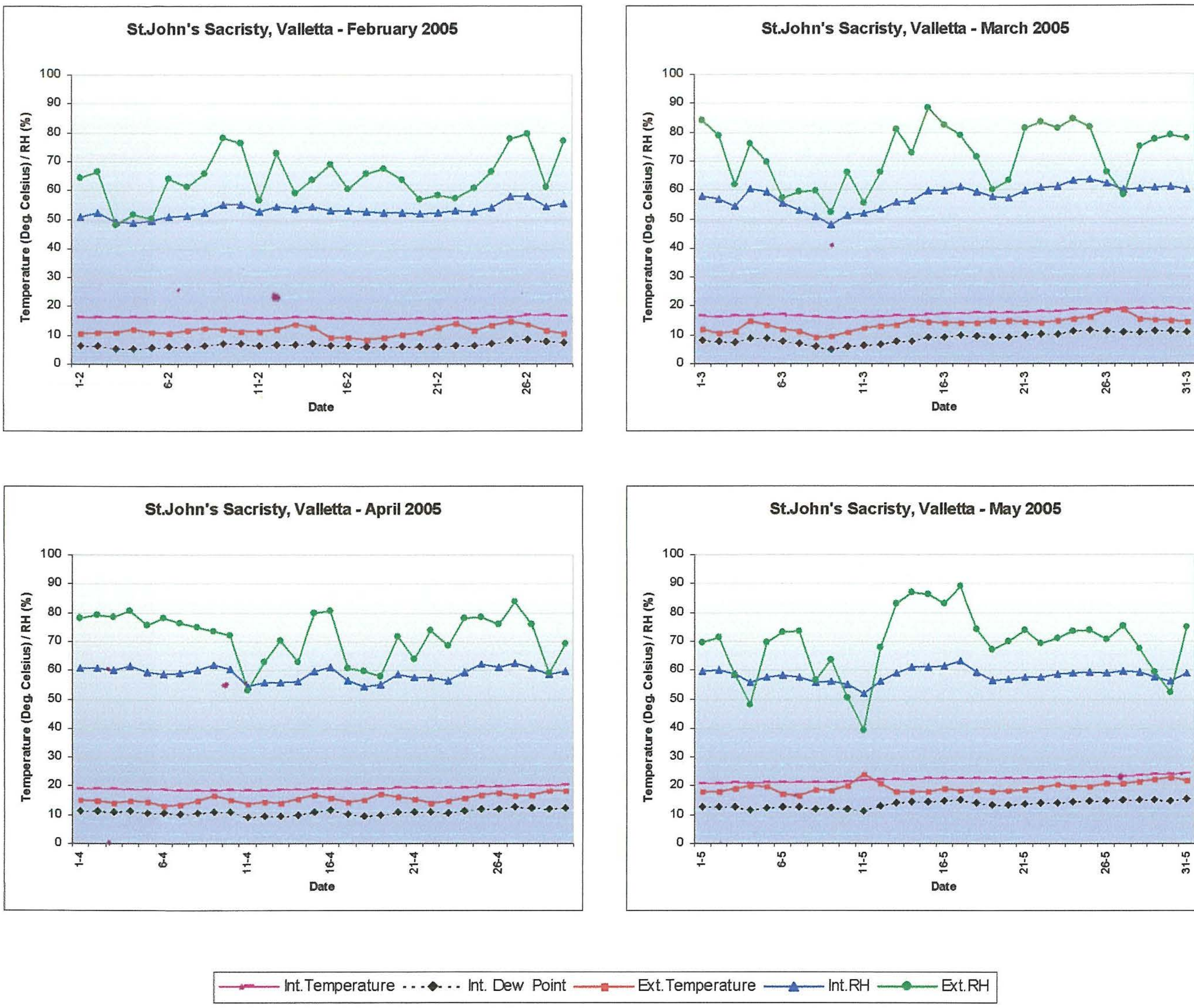

Figure 8 Mean daily relative humidity and temperature – Valletta, February 2005 - May 2005

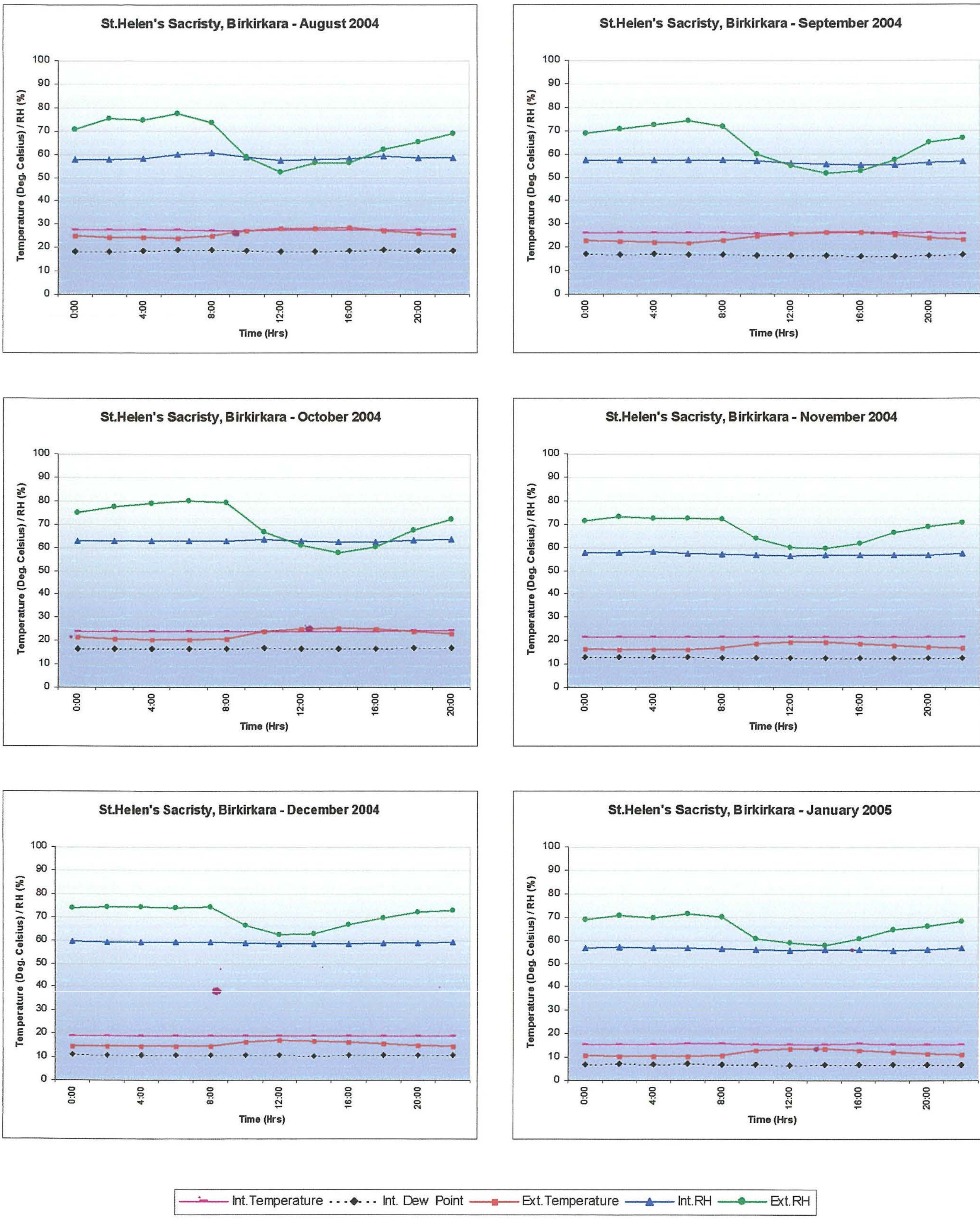

Figure 9 Mean bi-hourly readings - Birkirkara, August 2004 - January 2005

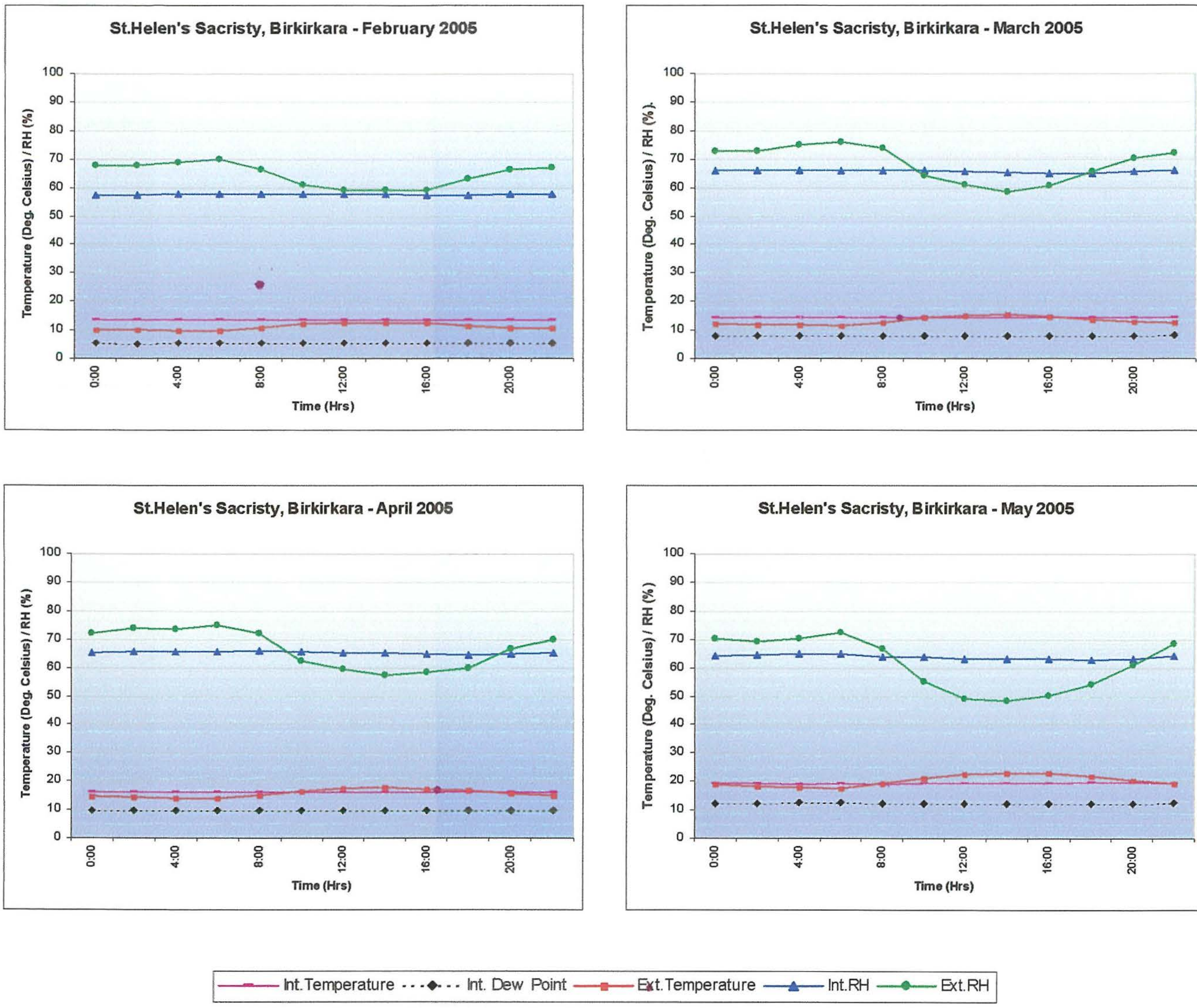

Figure 10 Mean bi-hourly readings – Birkirkara, February 2005 - May 2005

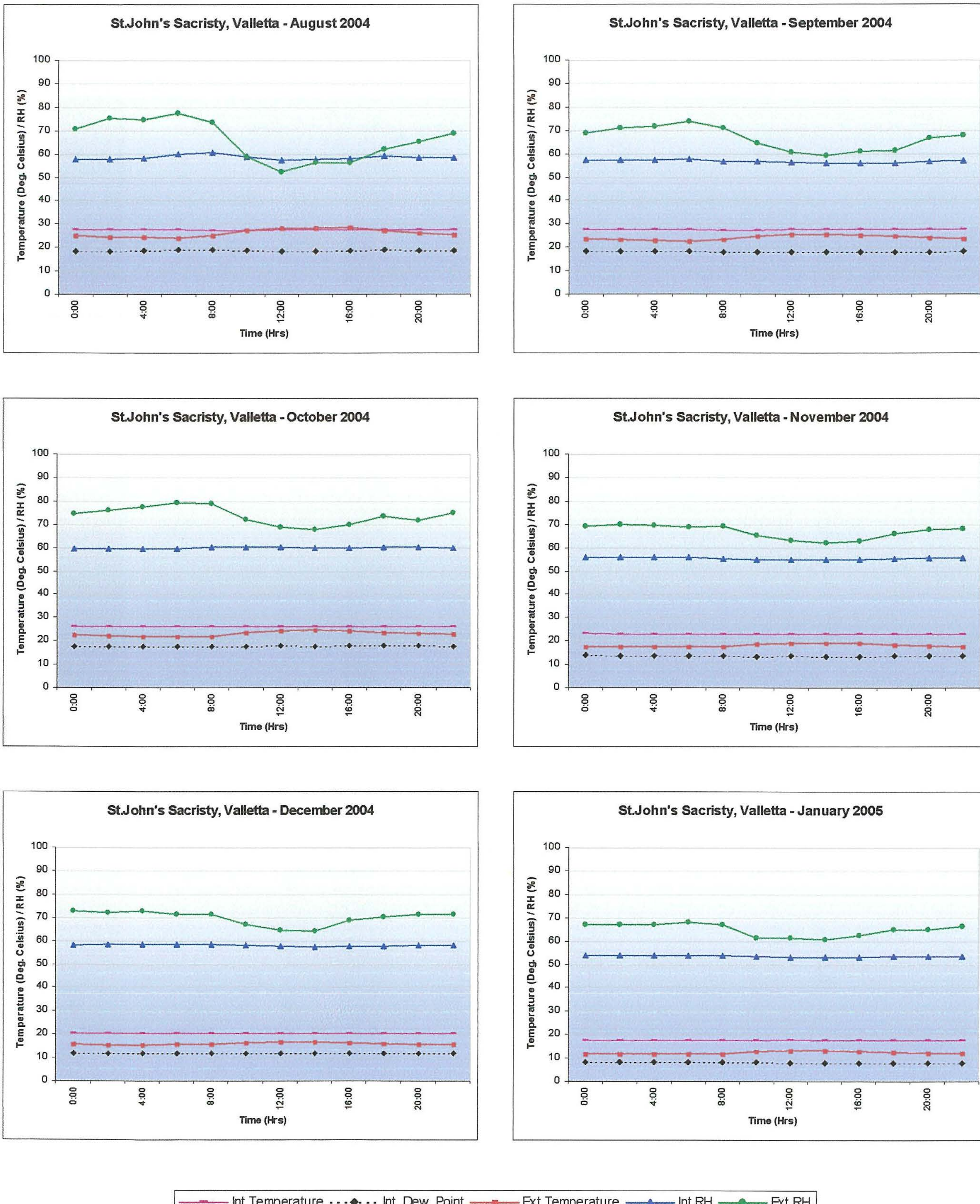

Figure 11 Mean bi-hourly readings – Valletta, August 2004 - January 2005

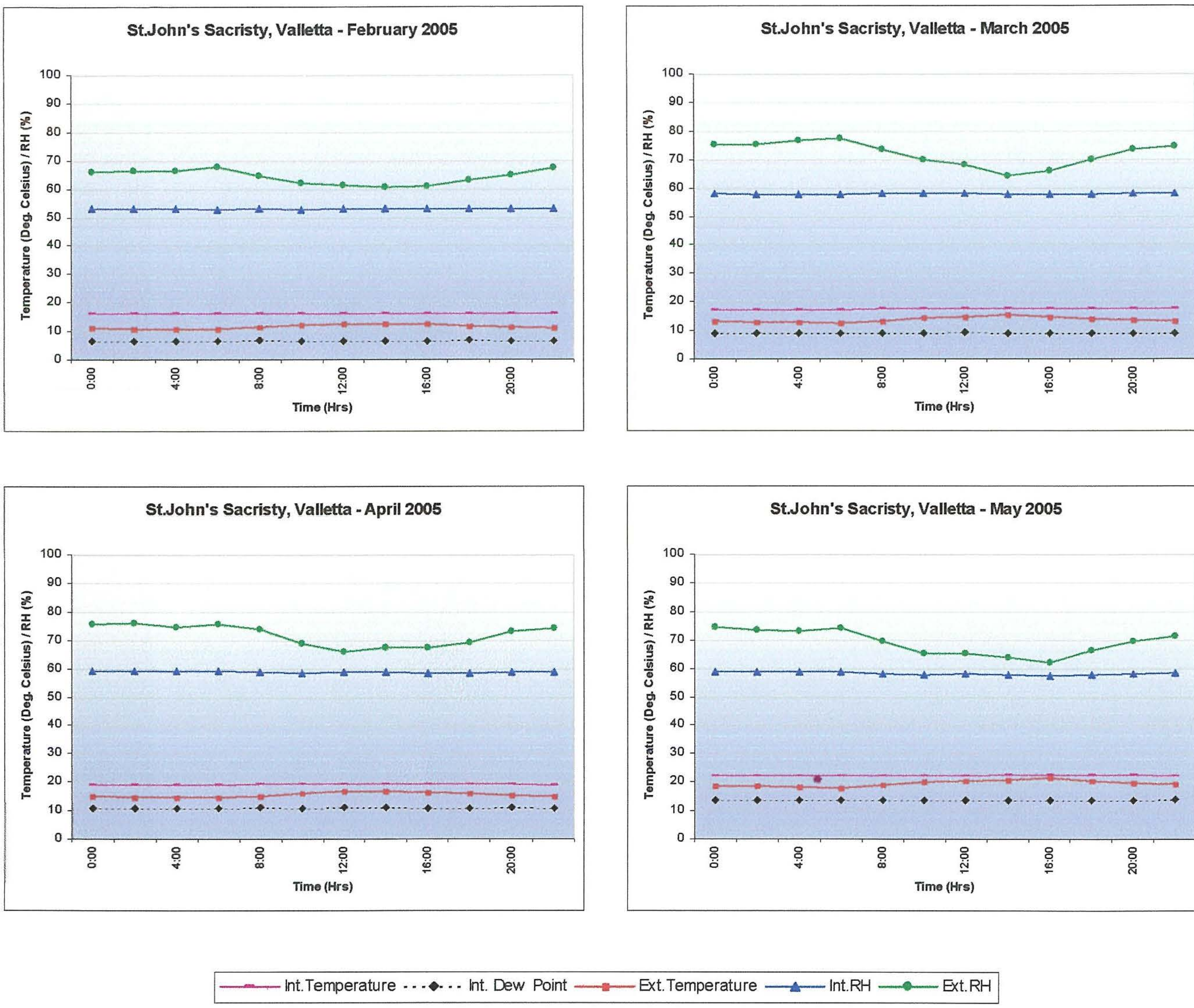

Figure 12 Mean bi-hourly readings – Valletta, February 2005 - May 2005

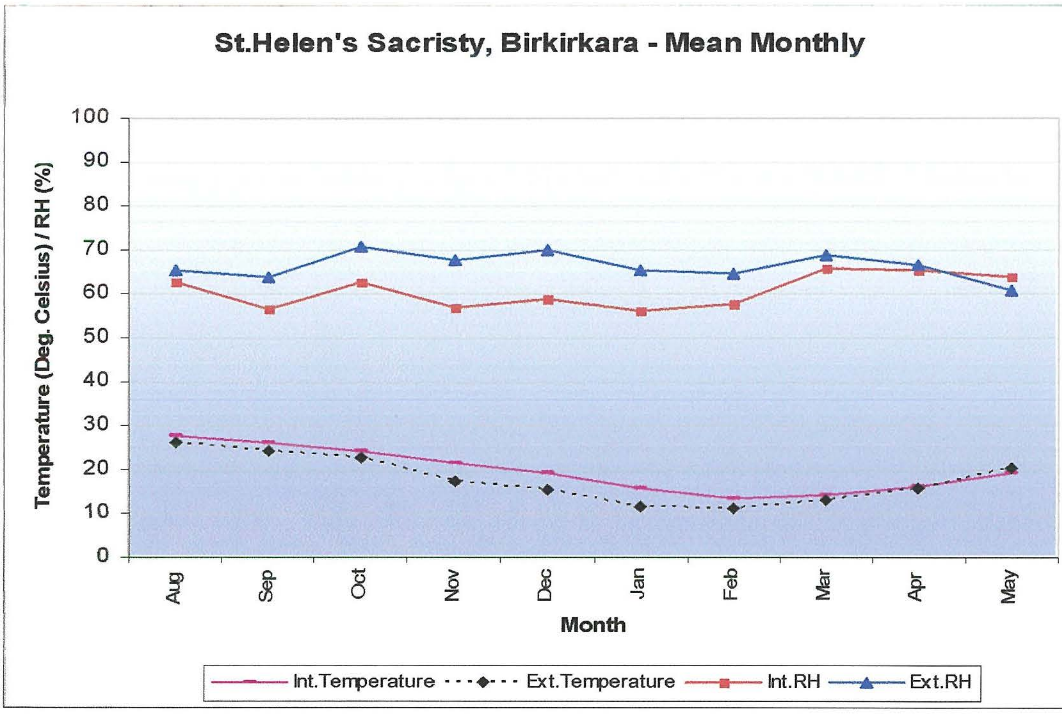

Figure 13 Mean monthly relative humidity and temperature – Birkirkara (Aug 04 - May 05)

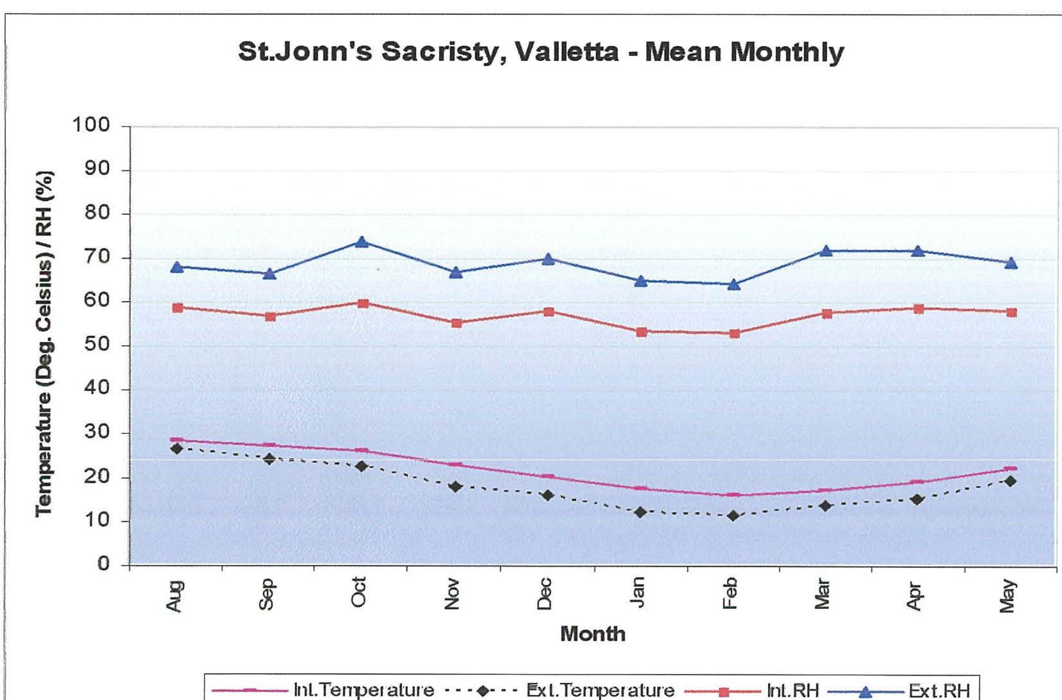

Figure 14 Mean monthly relative humidity and temperature – Valletta (Aug 04 - May 05)

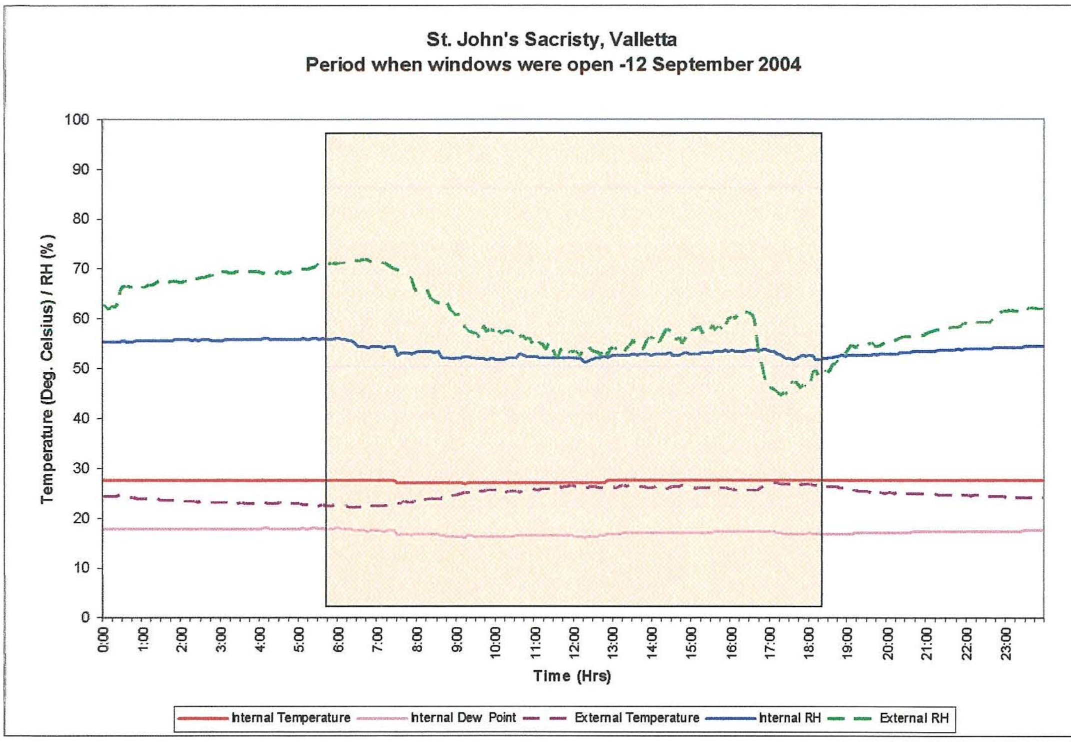

Figure 15 Monitoring of St John's sacristy over 24 hours indicating period when the windows were opened

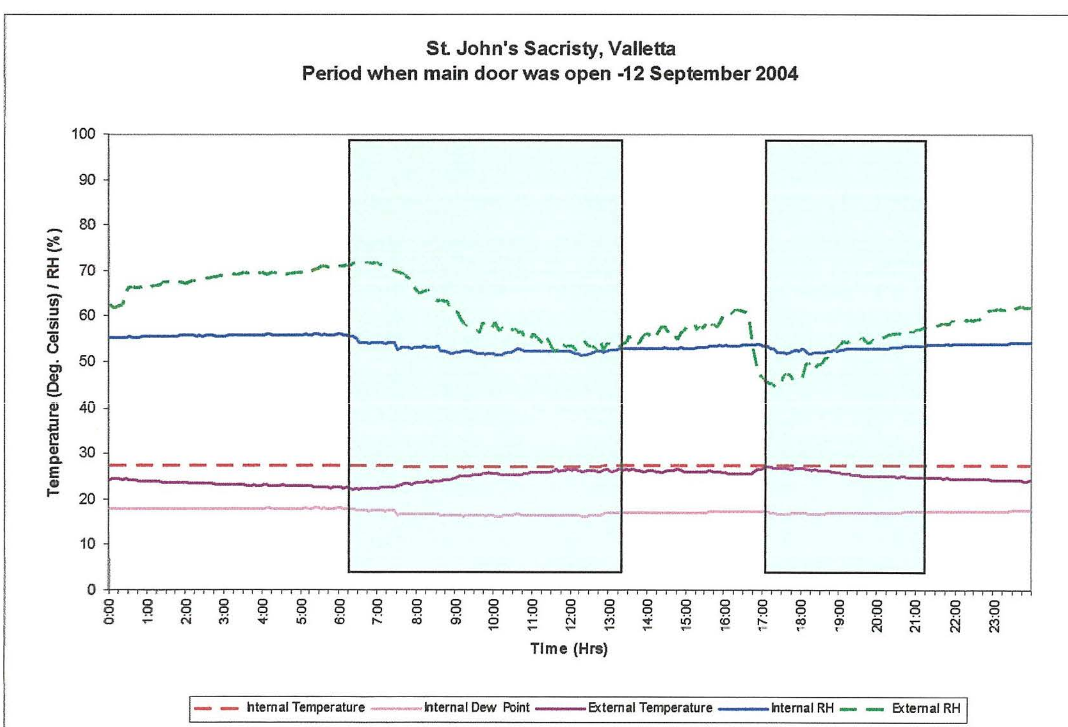

Figure 16 Monitoring of St John's sacristy over 24 hours indicating period when the main door was opened

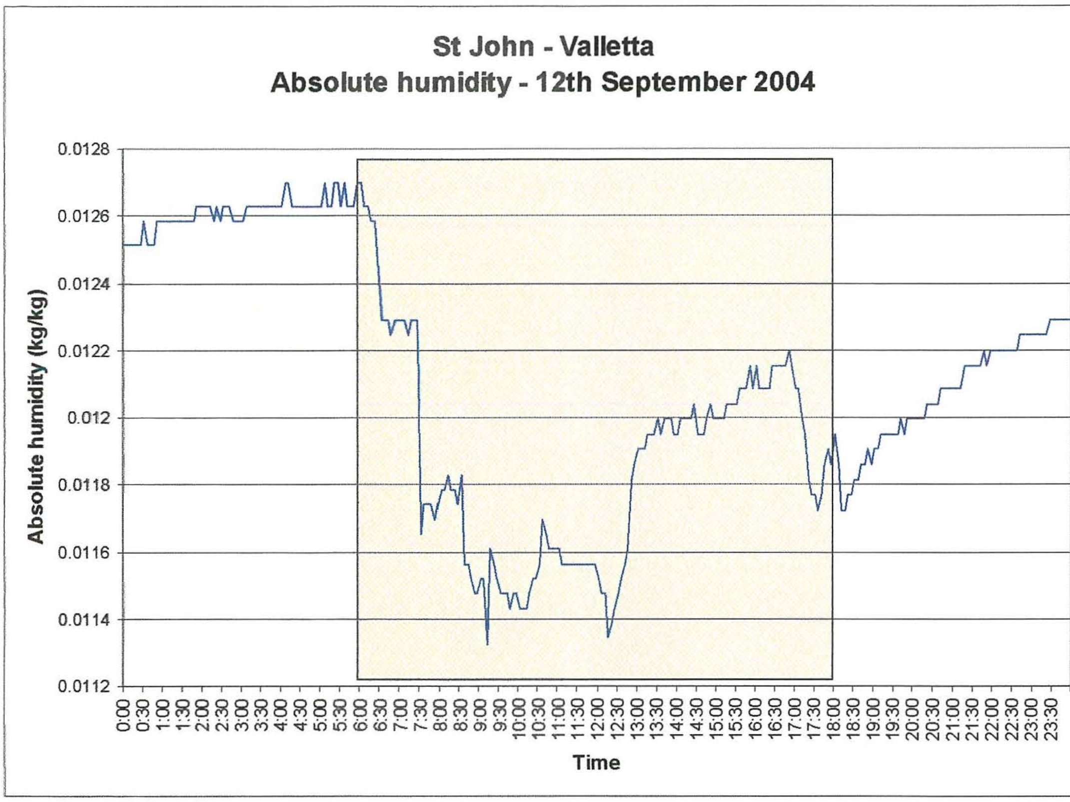

Figure 17 Absolute humidity in St John's sacristy over 24 hours indicating period when windows were opened

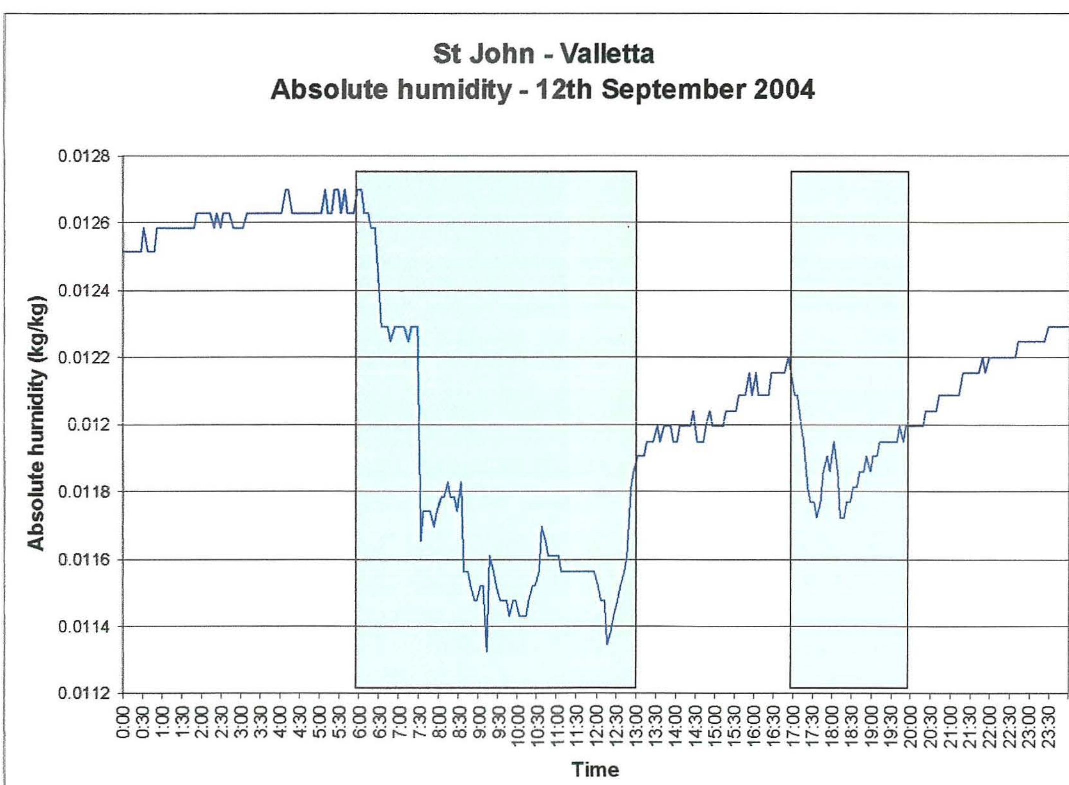

Figure 18 Absolute humidity in St John's sacristy over 24 hours indicating period when the main door was opened

Wood moisture content chart

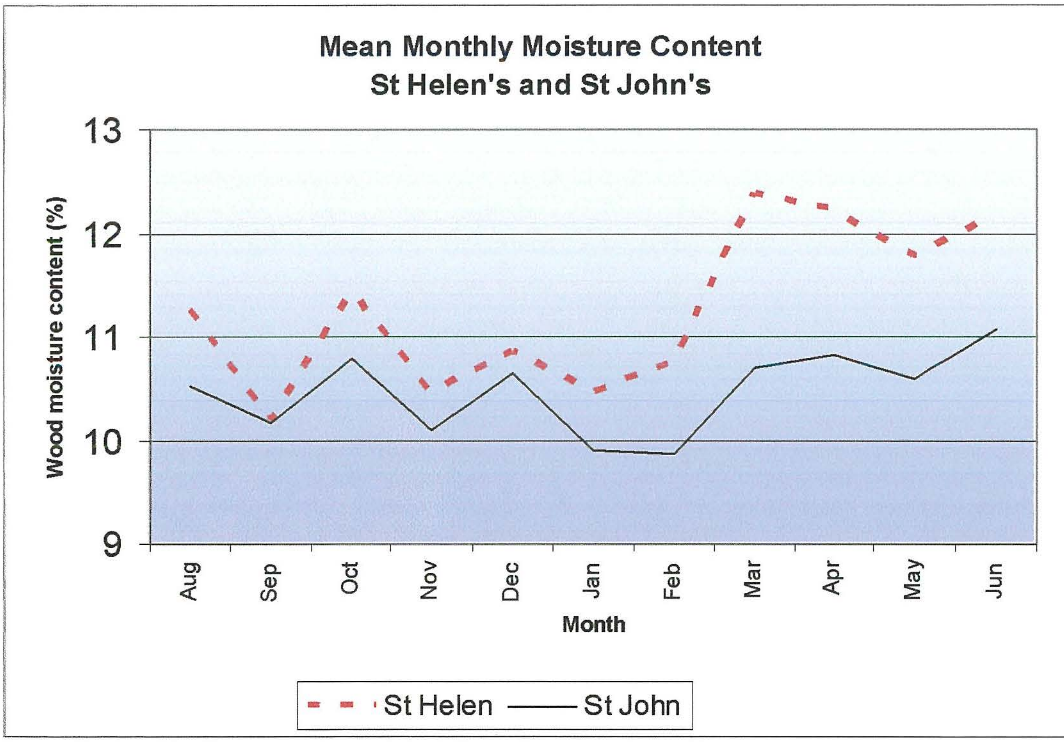

Figure 19 Mean monthly wood moisture content for the sacristies of St Helen's Basilica and St John's Conventual Church

Charts representing variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae

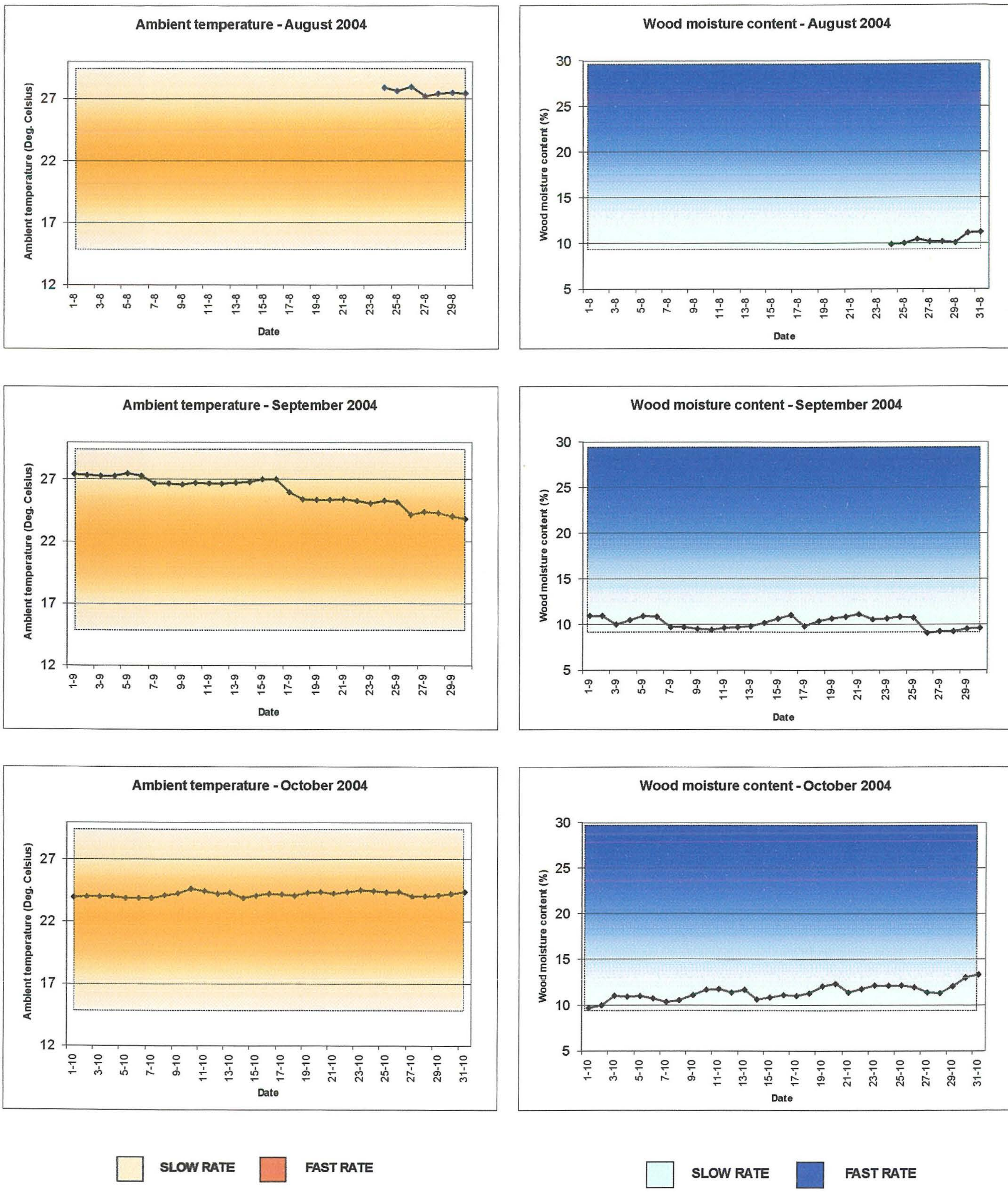

Figure 20 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Birkirkara, August 2004 – October 2004[3]

[3] Figures 20 to 27 were adapted from Nicolaus, (1999) 30.

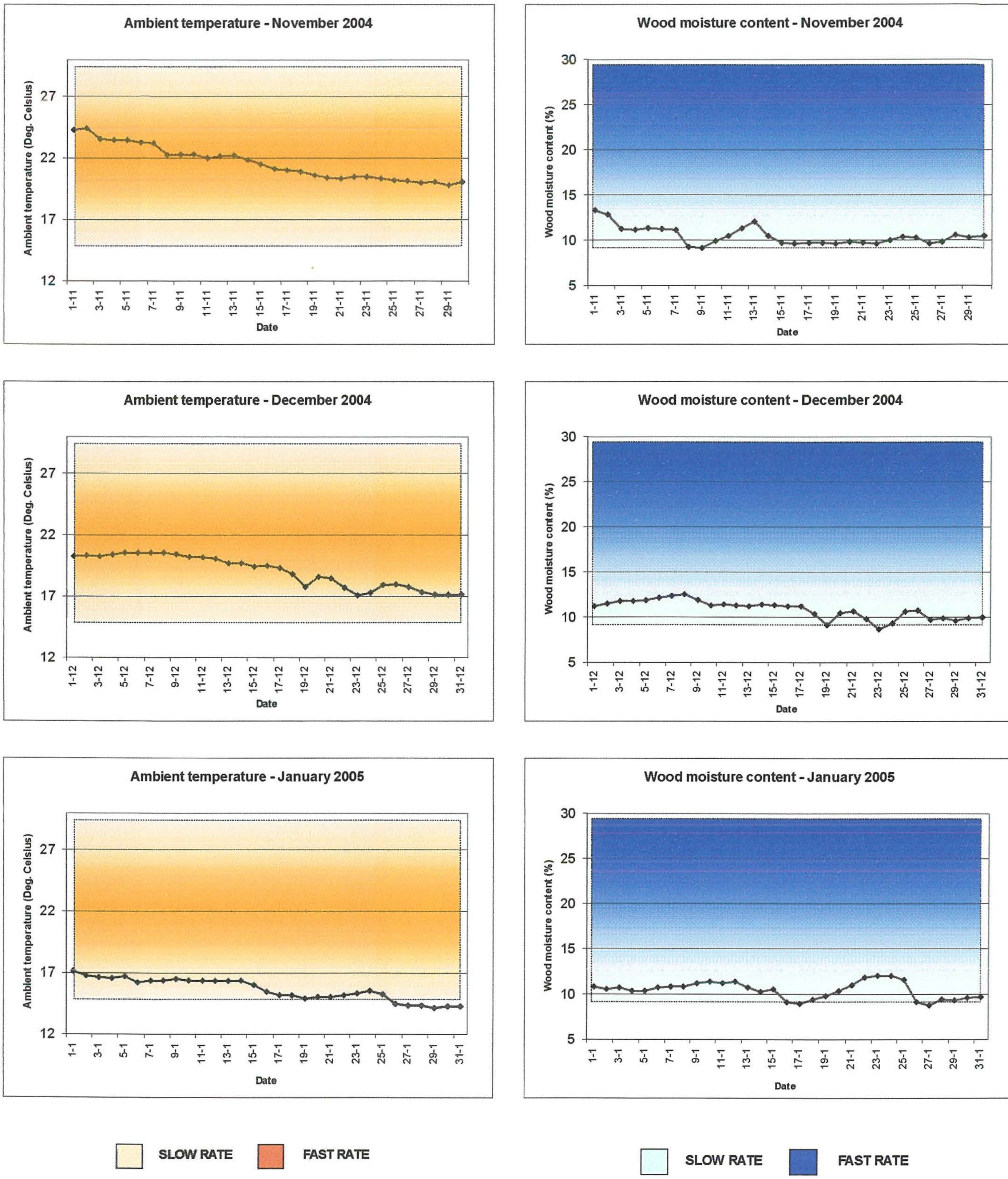

Figure 21 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Birkirkara, November 2004 – January 2005

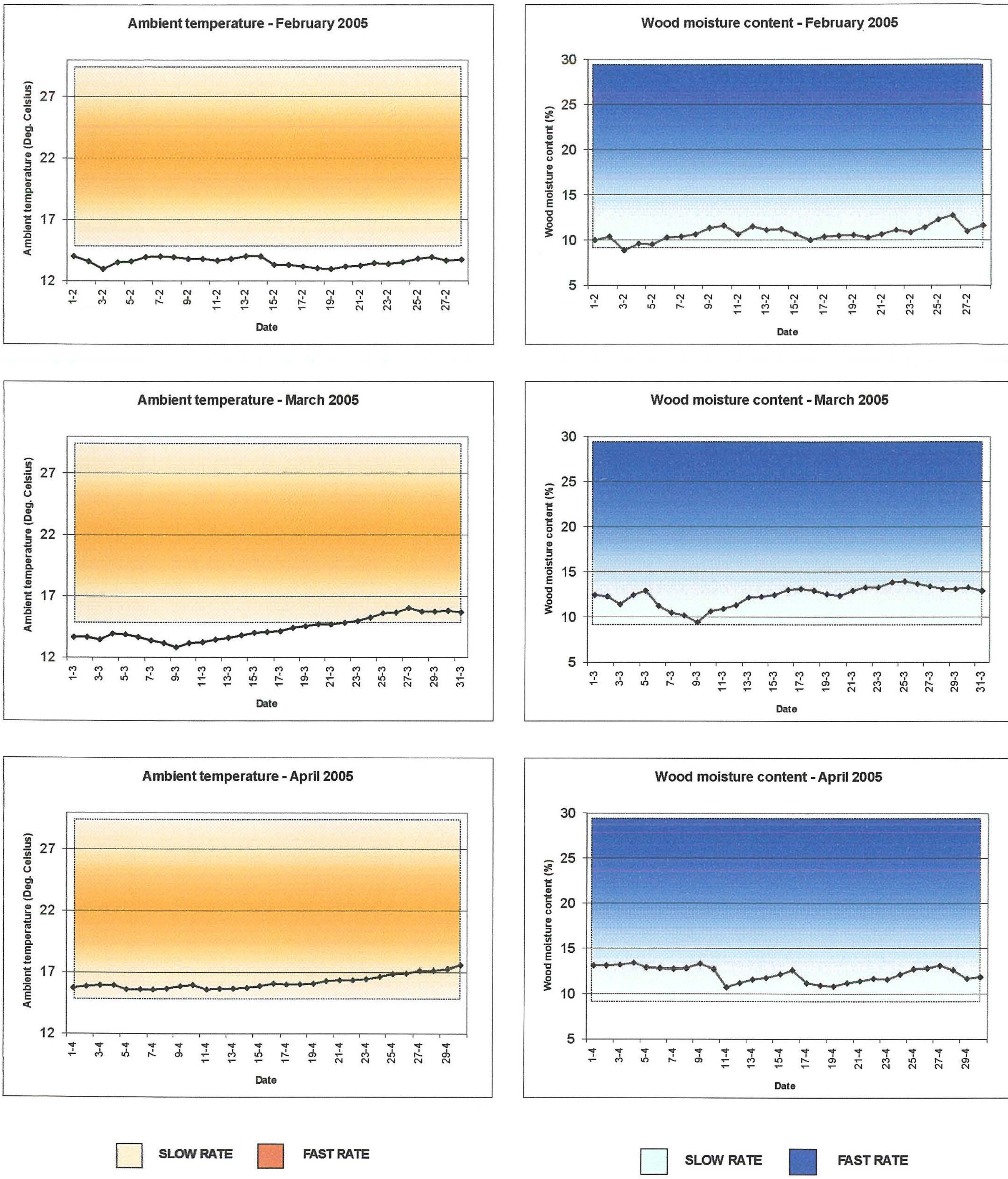

Figure 22 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Birkirkara, February 2005 – April 2005

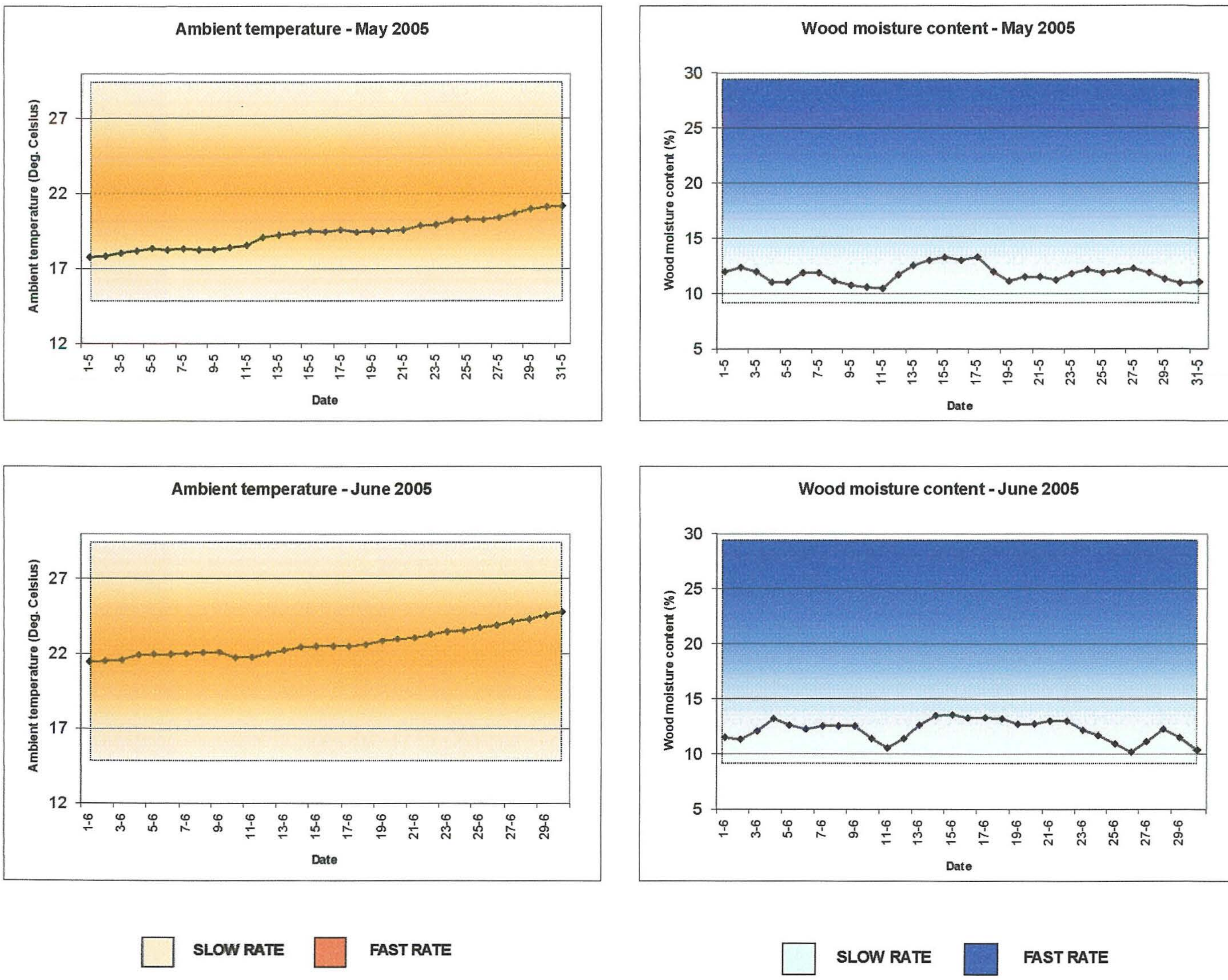

Figure 23 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Birkirkara, May 2005 – June 2005

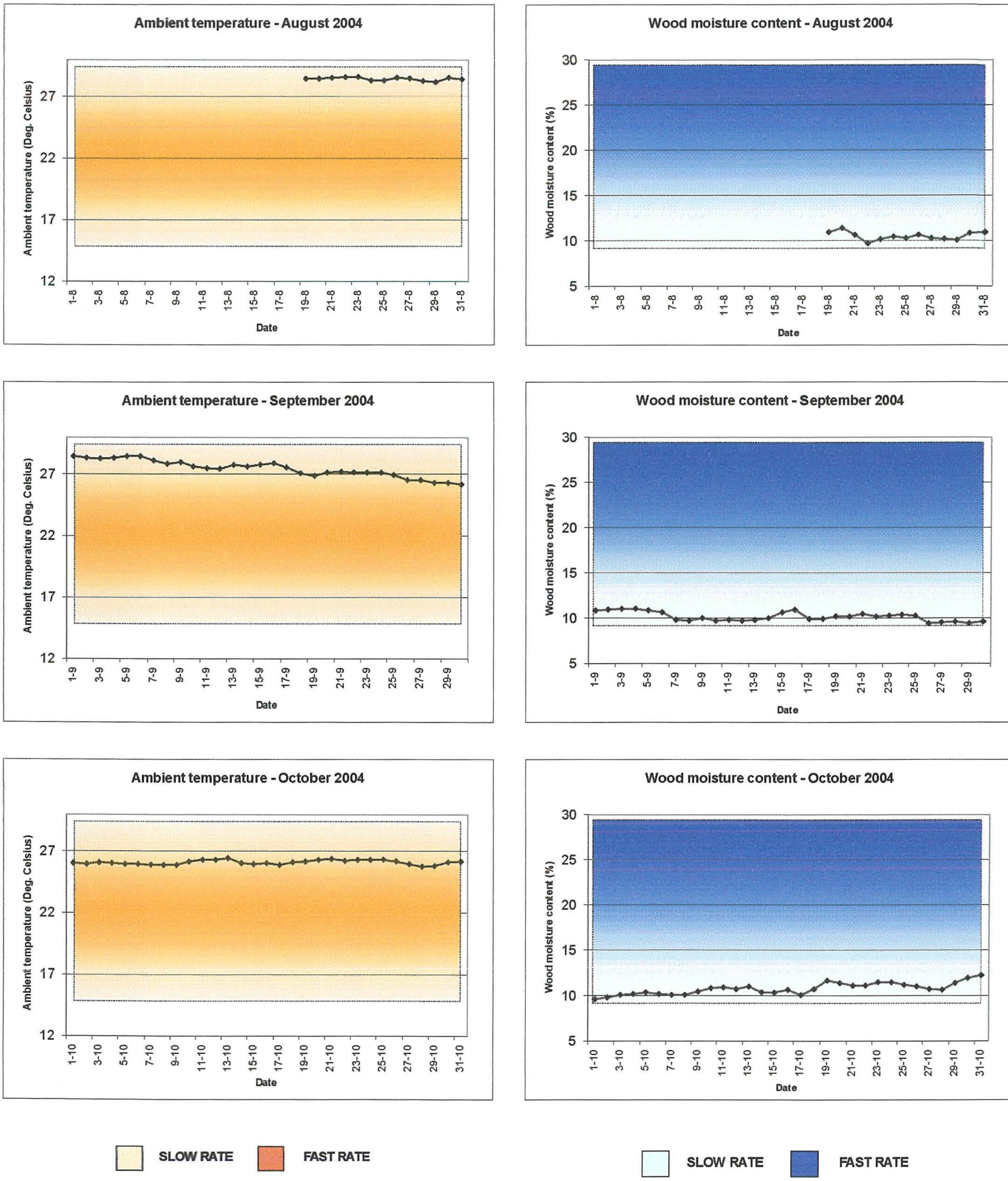

Figure 24 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Valletta, August 4004 – October 2004

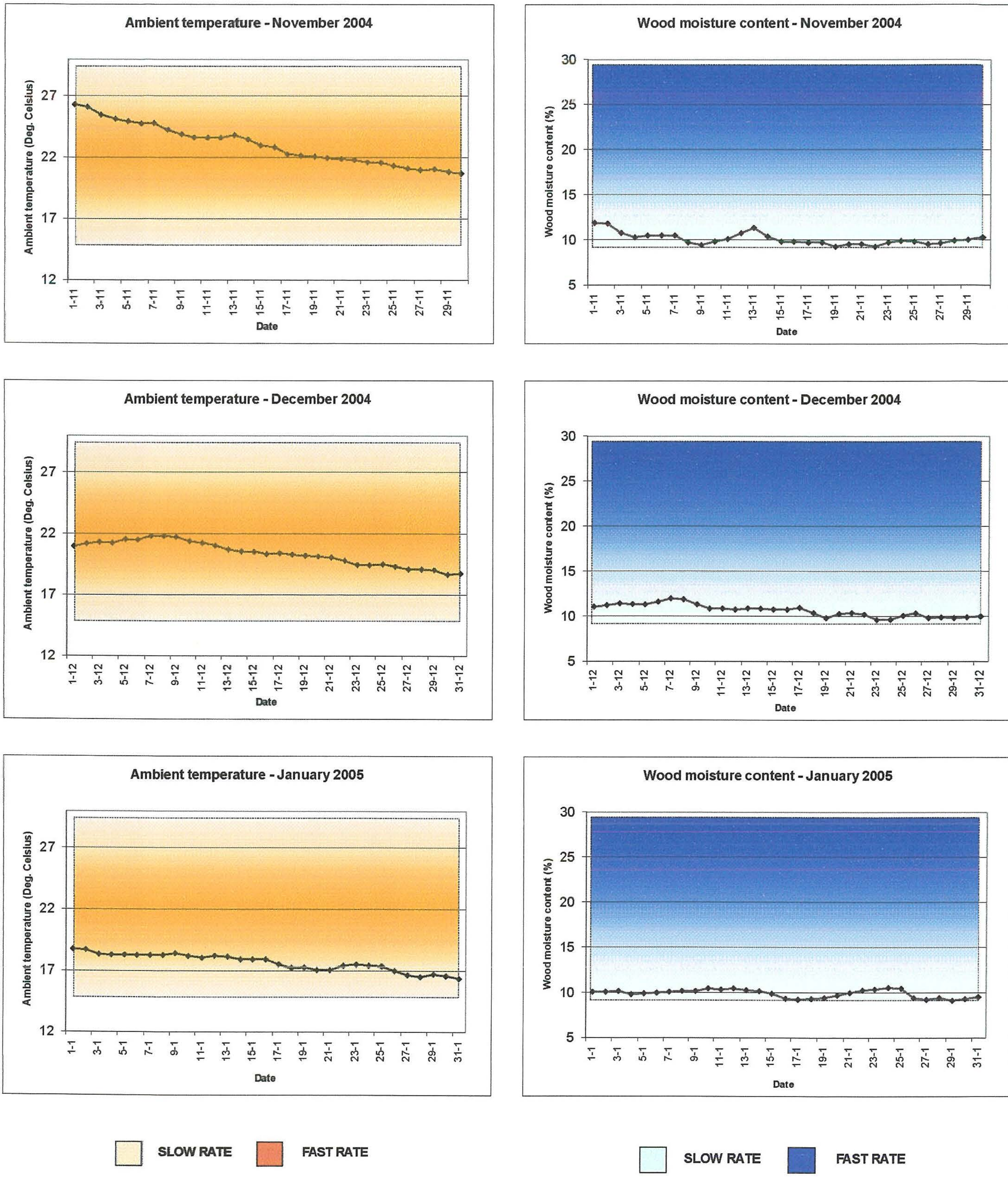

Figure 25 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Valletta, November 2004 – January 2005

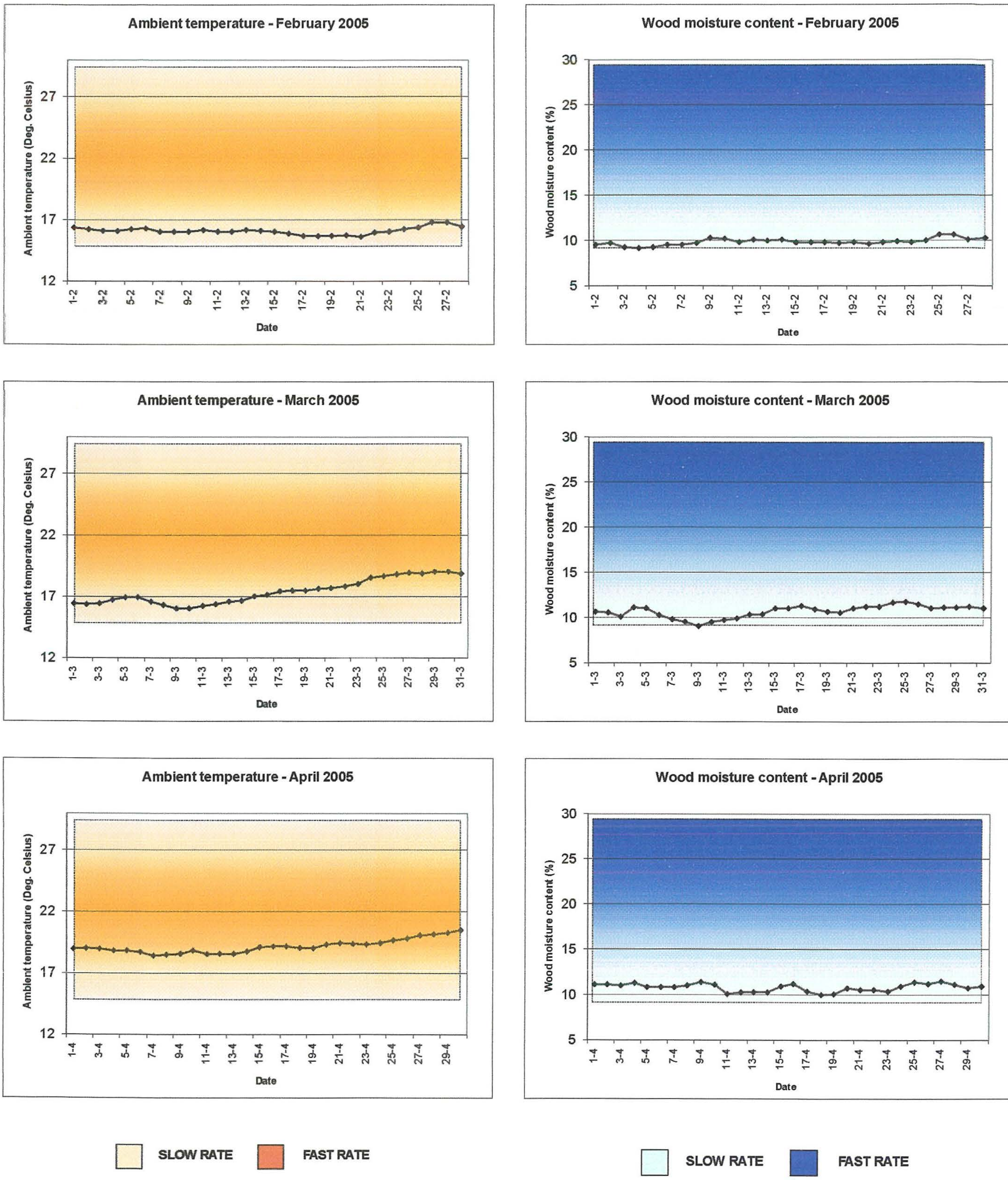

Figure 26 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Valletta, February 2005 – April 2005

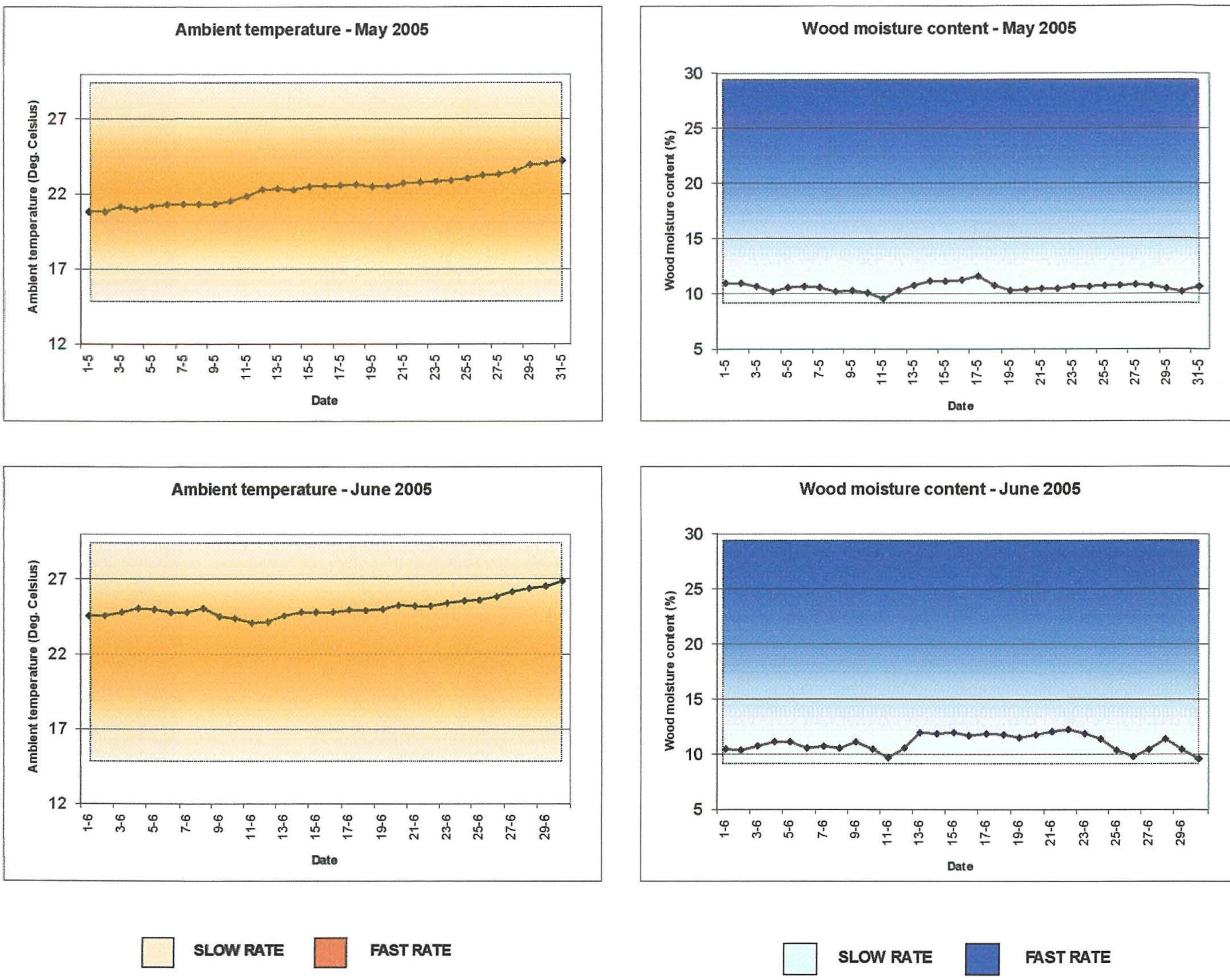

Figure 27 Variations in ambient temperature and wood moisture content that predict the rate of development of *Anobium punctatum* larvae – Valletta, May 2005 – June 2005

Mould activity charts

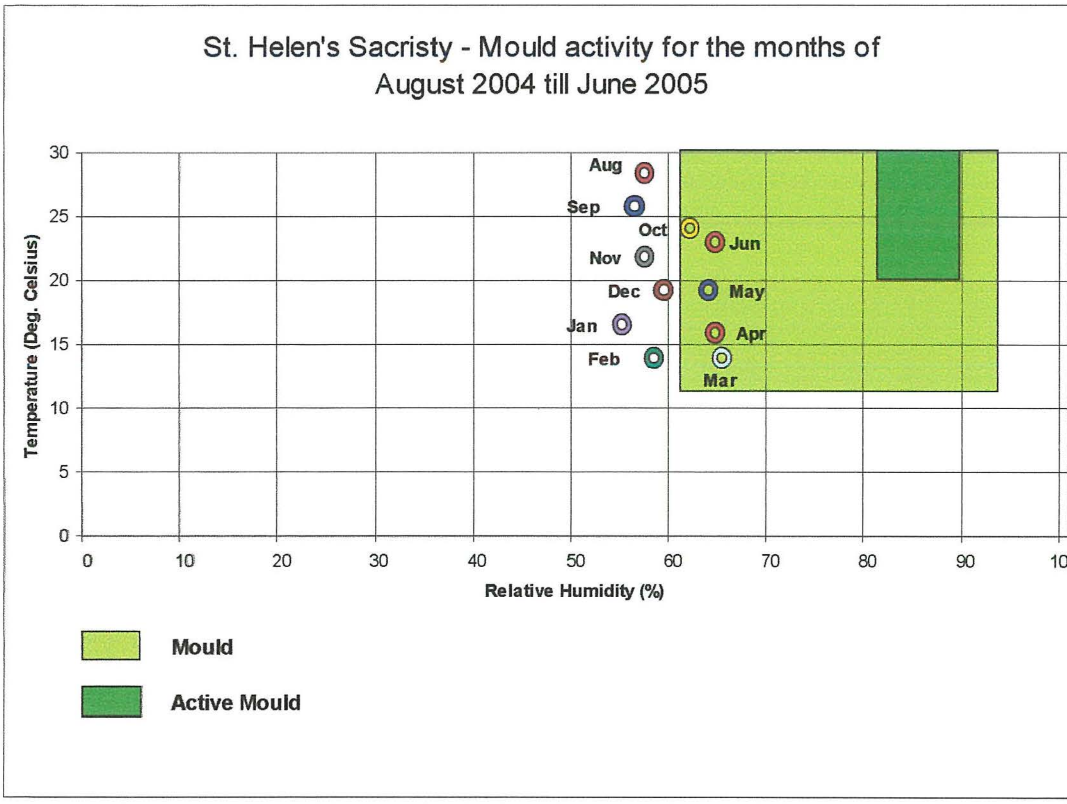

Figure 28 Mould activity for St Helen's Basilica, Birkirkara –August 2004 to June 2005

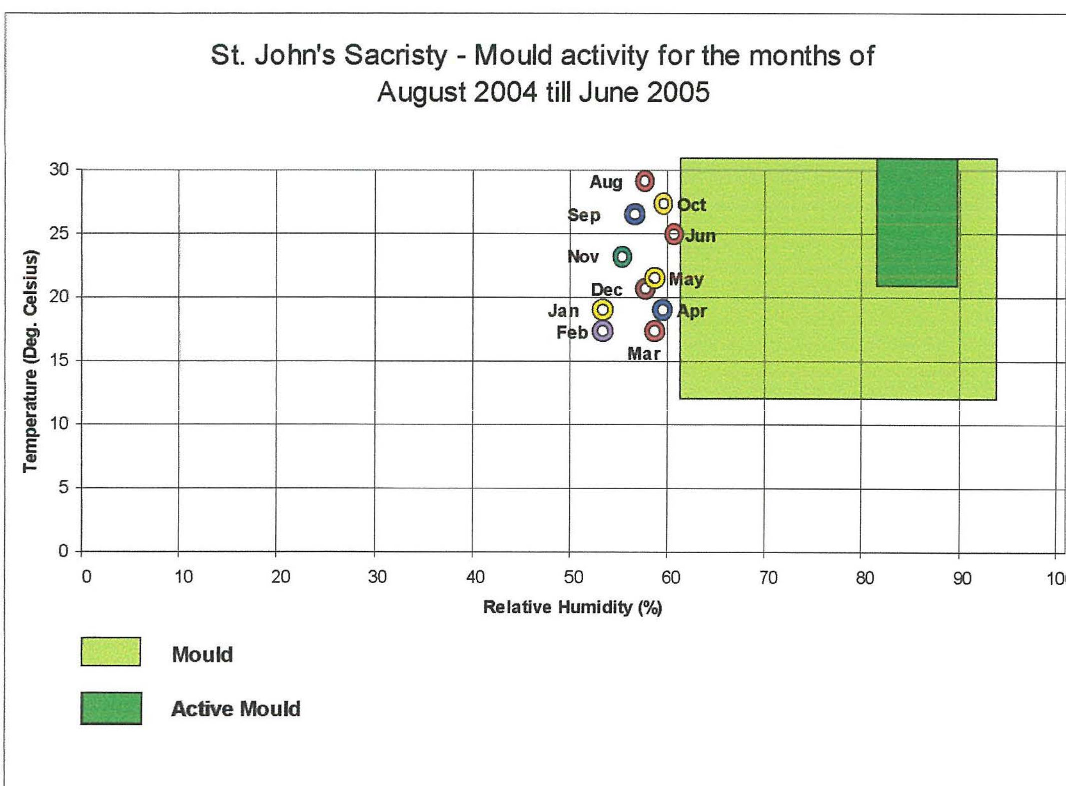

Figure 29 Mould activity for St John's Conventual Church, Valletta –August 2004 to June 2005

Light measurement charts

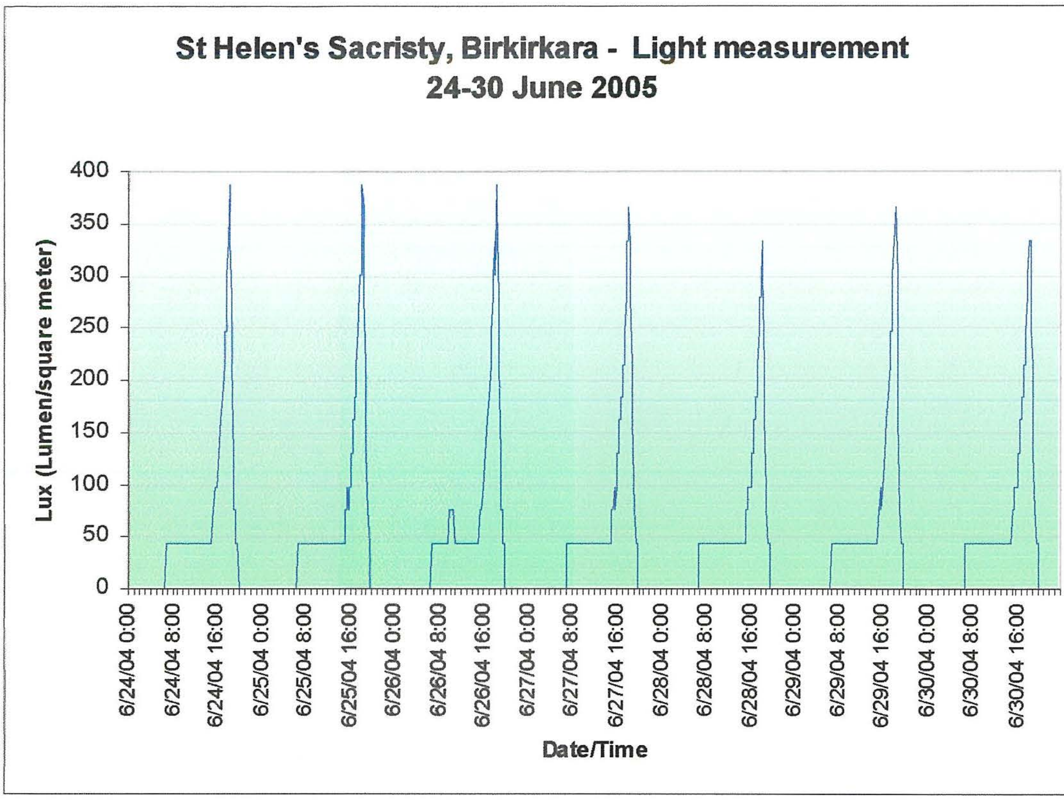

Figure 30 Light measurement for St Helen's Basilica, Birkirkara – 24-30 June 2005

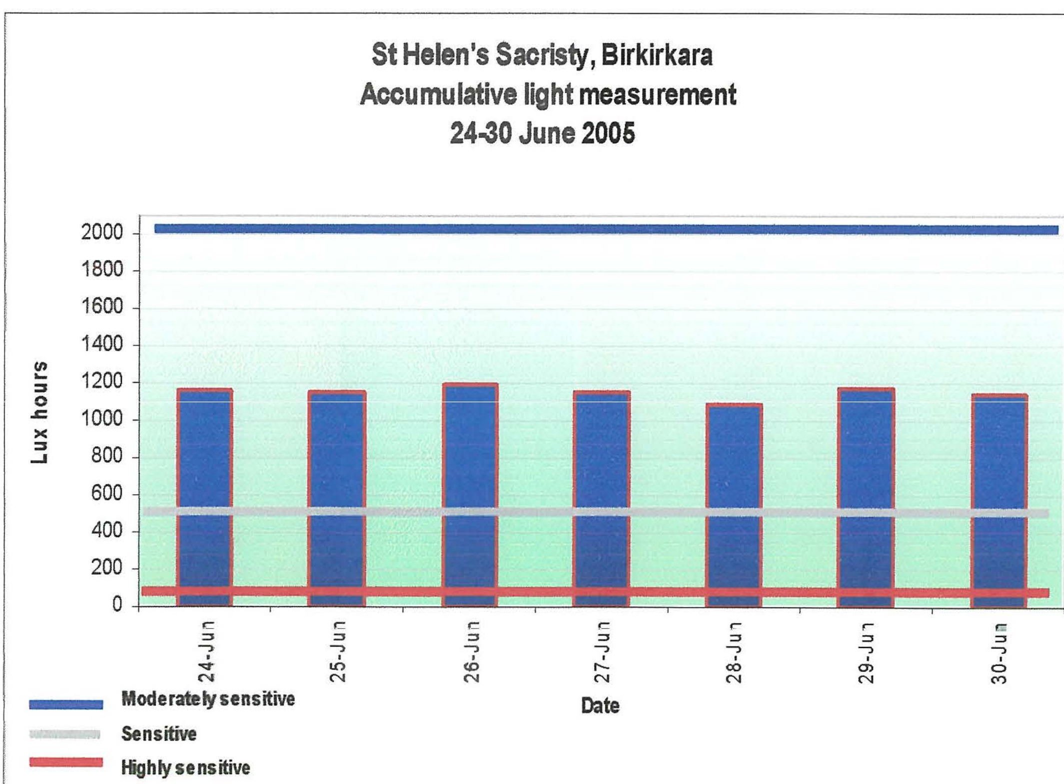

Figure 31 Accumulative light measurement for St Helen's Basilica, Birkirkara – 24-30 June 2005

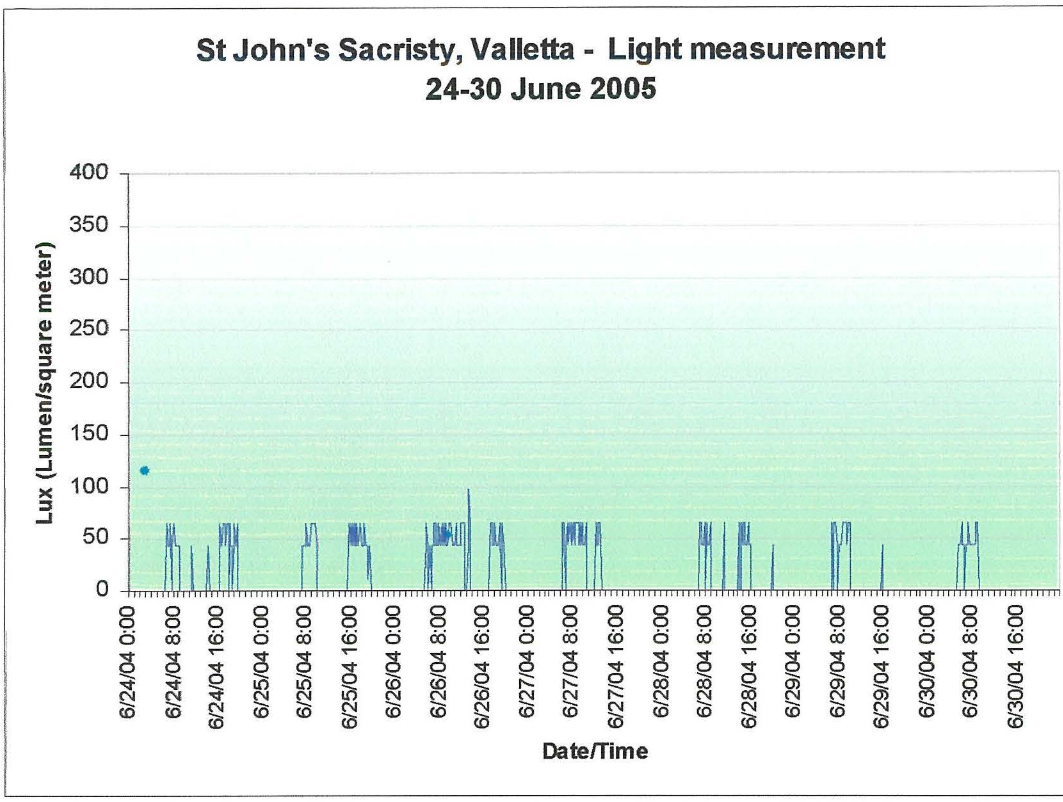

Figure 32 Light measurement for St John's Conventual Church, Valletta – 24-30 June 2005

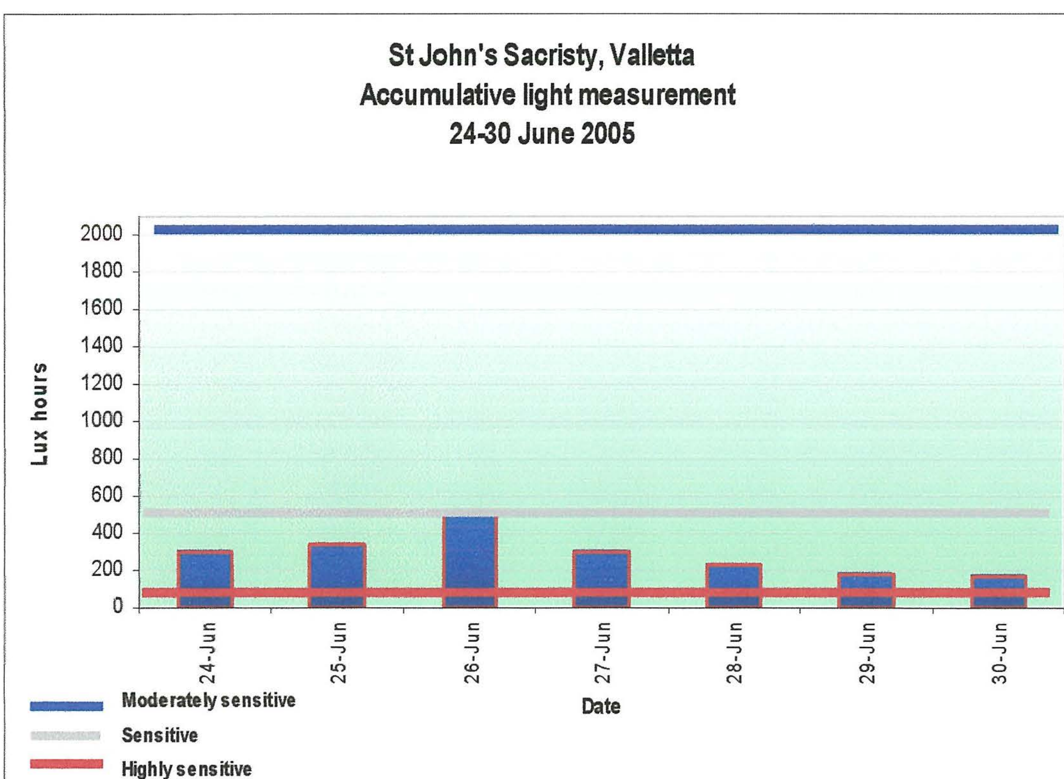

Figure 33 Accumulative light measurement for St John's Conventual Church, Valletta – 24-30 June 2005

Appendix 3 – Calculations and predictions of wood behaviour by computation

Computer program

1 Aim: The objectives of the computer software routine analysis were to predict linear dimensional changes and any possible ensuing warping (cupping) that may take place as a result of changes in ambient conditions.[1]

2 Introduction

A sample of wood was actually subjected to a 100% RH level for some days until FSP was reached and it was noticed that the actual dimensional changes and resulting warping were very similar to the predictions obtained by the software program analysis.[2]

3 Method

Two computer software packages were used, namely, Microsoft Excel and AutoCAD 2000. By gathering information from relevant literature, it was possible to formulate the necessary procedure that leads to the production of the final predictions regarding the behaviour of wood.

There four main stages of this procedure are:[3]

1. Generation of end grain and line drawing using AutoCAD
2. Insertion and merging of data into Excel
3. Interpretation of data and relevant calculations using Excel
4. Re-construction of the panel end grain showing contraction/expansion and warping using AutoCAD.

2.2 Generation of end grain and line drawing by AutoCAD

The initial step was to obtain as much information as possible on the end of the given piece of wood. This information consists of taking accurate measurements of the wood sample, including the data regarding any deformations such as warping. An essential part of such information is the end grain and its layout with respect to the

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[1] Formosa, (2003) 59.
[2] Ibid., 67.
[3] Ibid., 60.

growth rings. It is of utmost importance to obtain an accurate picture or drawing of the end grain, which must be extremely accurate. One must realise that the end grain configuration will eventually determine the actual expansion/contraction as well as any warping that may take place after changes in ambient conditions. Small samples may be directly scanned with a simple computer scanner. Photography introduces an element of inaccuracy due to perspective illusion. If conventional or digital photography is used, the picture ought to be taken from a distance so as to minimise distortions, or else make use of digital photography at a close distance and take a series of macro-photographs which can be later stitched into one picture.[4]

In this study, two specific parts from two different pieces of furniture were tested: one lid from a lower cupboard from the sacristy of St Helen's basilica in Birkirkara, and a door panelling from the sacristy of St John's in Valletta. While in the former case a precise sketch of the orientation of the growth rings was constructed, in the case of the Valletta sacristy test digital photography was used. [Plates 1 and 2]

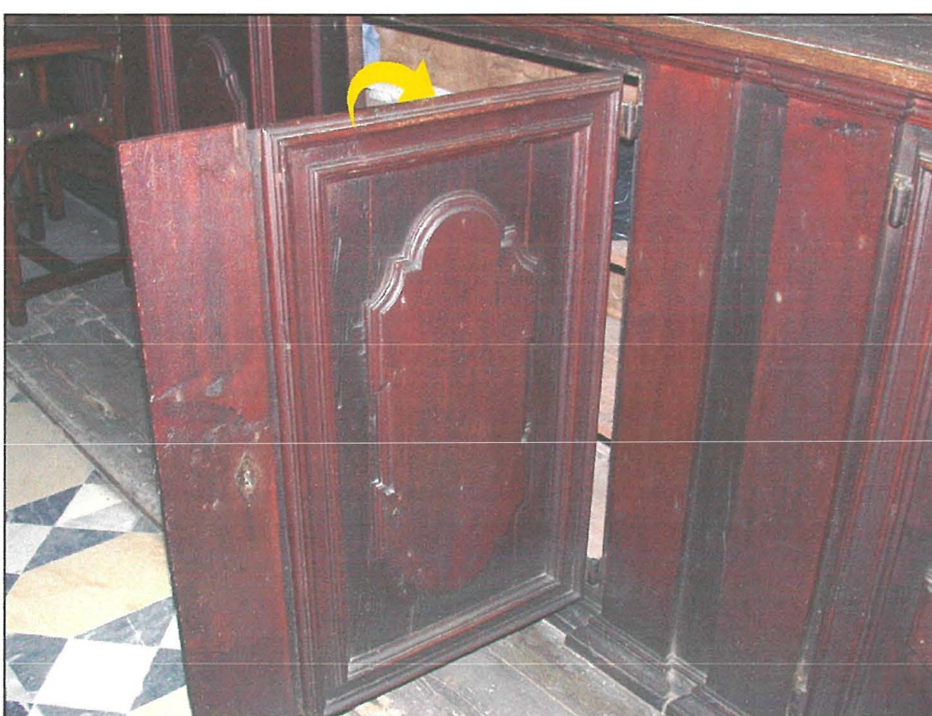

Plate 1 View of door used for prediction indicating the edge under study

[4] In this study, due to the fact that both samples were hinged permanently to the furniture, digital photography was accompanied by accurate sketches of the end grain of such samples.

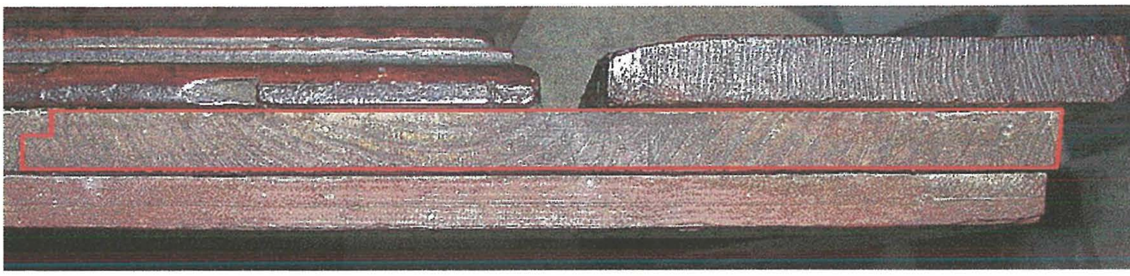

Plate 2 Digital image of Board 3 from above, showing the growth rings

To facilitate the marking of the individual timber growth rings, some pre-processing was necessary. [Plate 3]. Software programs such as Adobe Photoshop, Corel Photo Paint or any other bitmap processing software may be used to enhance the image, more specifically adjusting hues, brightness and contrast. Most photo enhancing packages that are supplied with scanners and digital cameras should also be sufficient for this purpose.

Plate 3 Board 3 following enhancement of the image by Adobe Photoshop

The photograph was then transferred into AutoCAD and the outline was traced. The panel was subsequently virtually divided into small units. [Plate 4] The width of each unit is determined by the amount of change in the tangential direction of the growth rings: the bigger the change in direction, the narrower the width of the said virtual units, and, likewise, the smaller the radius of the given growth ring, the smaller the width of resulting elements. For each rectangular virtual element, the two diagonals are also drawn. The tangential direction of the growth ring is subsequently marked on each section. [Plate 5]

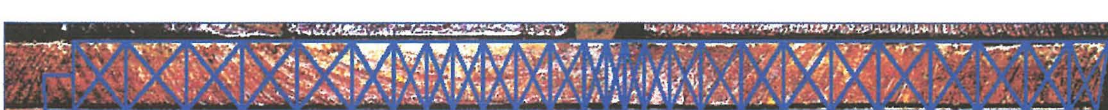

Plate 4 Board 3 divided into several virtual sections

Plate 5 Board 3 showing the virtual divisions and the direction of the growth ring

Figure 1 is a simple example showing three elements and the six main lines of each element together with the tangential orientation of the growth rings.

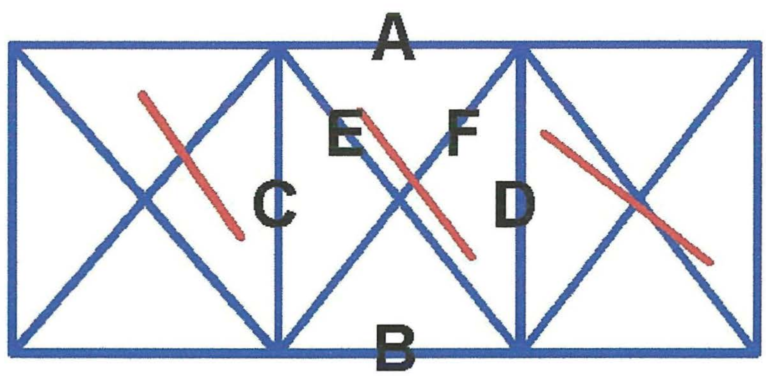

Figure 1 AutoCAD drawing showing the six main lines of each element (marked A to F) as well as the tangential orientation of the growth rings (red line)

The next step consisted of the measurement of the lengths of the sides and diagonals of each element (marked A to F in Figure 1) as well as the angles of orientation with respect to the direction of the tangential growth ring (0° to 90°). These measurements (lengths of sides and angles for each virtual element) were carried out by using AutoCAD itself. This means that a set of six lengths and six angles were obtained for each element.[5] The example shown for Board 3 of the Valletta sacristy door, Plate 5, had 27 virtual elements and therefore 162 lengths and 162 angles were recorded. This stage proved to be very time consuming. Figure 2 shows an example of different grain directions which are the consequence of the actual rate of expansion/contraction and, as a result, the amount of warping. In this example board no. 2 is more prone to warping.[6]

[5] Formosa, (2003), Appendix 5, pg. 5.
[6] Ibid., 60.

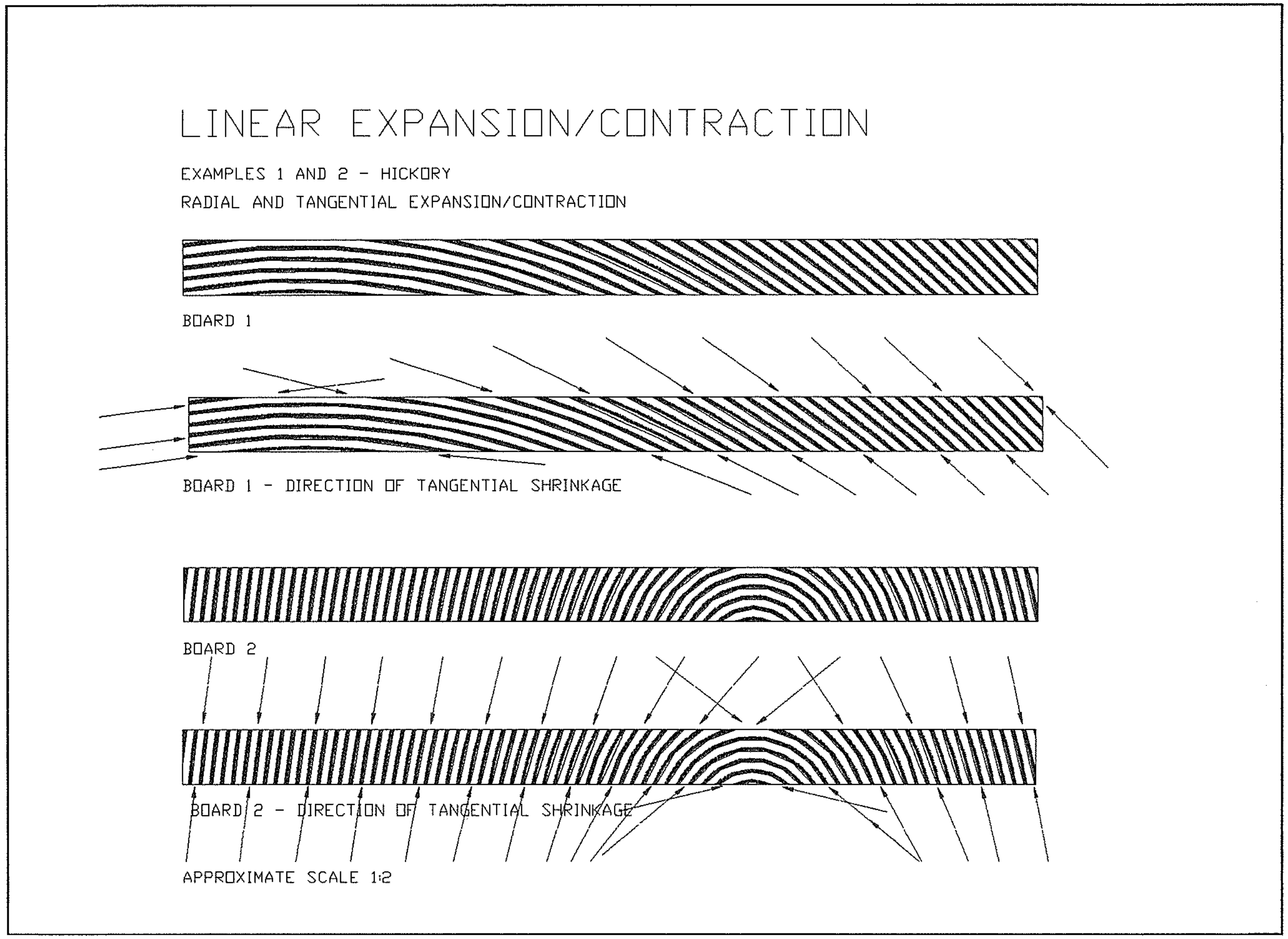

Figure 2 Two board sections showing different directions of tangential shrinkage[7]

[7] Formosa, (2003) 63.

Table 1 shows the information inserted into the Microsoft Excel worksheets for elements 3.1, 3.2, 3.3 and 3.4.

Section		Initial Dim mm	Orientation deg
3.1	A	**8.00**	**32**
	B	**8.00**	**32**
	C	**10.00**	**58**
	D	**10.00**	**58**
	E	**12.81**	**97**
	F	**12.81**	**19**
Section		Initial Dim (mm).	Orientation (deg)
3.2	A	**14.76**	**36**
	B	**14.76**	**36**
	C	**19.56**	**54**
	D	**19.56**	**54**
	E	**24.50**	**89**
	F	**24.50**	**17**
Section		Initial Dim (mm).	Orientation (deg)
3.3	A	**16.92**	**35**
	B	**16.92**	**35**
	C	**19.56**	**55**
	D	**19.56**	**55**
	E	**25.86**	**84**
	F	**25.86**	**14**
Section		Initial Dim (mm).	Orientation (deg)
3.4	A	**15.48**	**38**
	B	**15.48**	**38**
	C	**19.56**	**52**
	D	**19.56**	**52**
	E	**24.94**	**90**
	F	**24.94**	**14**

Table 1 Data collected from the AutoCAD exercise, subsequently inserted into a Microsoft Excel worksheet

The data reporting the initial and final ambient conditions together with published literature data for the specific type of wood need to be included in the upper section of the designed worksheet. [Table 2][8] The Excel worksheet would, at this stage, be ready to

[8] The initial data refers to the actual dimensions, the RH and the T recorded when the board was measured and scanned/photographed. Note that, for this study, an average value over one month for RH and T was calculated and considered.

yield the required results. The main dimensions of the board were also inserted for general information. Below is the data required for the required calculations:[9]

- Initial and final T
- Initial and final RH
- Published literature value for longitudinal shrinkage[10]
- Published literature value for tangential shrinkage[11]
- Published literature value for radial shrinkage[12]
- Published literature value for the fibre saturation point (FSP)[13]

T*i*	Initial Temperature (Deg. Celsius)	16
T*f*	Final Temperature (Deg. Celsius)	14
RH*i*	Initial Relative Humidity (%)	53
RH*f*	Final Relative Humidity (%)	95
MC*i*	Initial Moisture Content (%)	9.86
MC*f*	Final Moisture content (%)	24.17
FSP	Published value for FSP (%)	30
S*t*	Published value for tangential shrinkage *t* (%)	7.4
S*r*	Published value for radial shrinkage *r* (%)	3.6
S*l*	Published value for longitudinal shrinkage *l* (%)	0.1
ΔD*t*	Dimensional change *t* (mm)	-0.037133536
ΔD*r*	Dimensional change *r* (mm)	-0.01759273
ΔD*l*	Dimensional change *l* (mm)	-4.76909E-05
Actual value for *t* shrinking (%)		-3.713353582
Actual value for *r* shrinking (%)		-1.759273035
Actual value for *l* shrinking (%)		-0.004769091
Initial linear dimension - side *a* (mm)		296.16
Linear dimensional gain/loss *a* (mm)		8.1090
Final linear dimension - side *a* (mm)		304.2690
Percentage linear gain/loss *a* (%)		102.7380618

Table 2 Excel worksheet showing the published literature data for wood as well as the initial and final relative humidity and ambient temperature levels for the sacristy door of St John's Conventual Church, Valletta

[9] Formosa, (2003) 62.
[10] This information will be left out if the longitudinal contraction/expansion will not be required for prediction. If the literature information is not available, a value of 0.1% will be assumed.
[11] When the value of a specific wood is not found in the literature, an average value of 8% will be used.
[12] When the value of a specific wood is not found in the literature, an average value of 4% will be used.
[13] When the value of a specific wood is not found in the literature, an average value of 30% will be used

Once the model has been recreated within the worksheet, one may vary the values of the final T and the final RH accordingly in order to obtain the required resulting lengths of the separate sides of the elements. [Table 3]

Section		Initial Dim (mm)	Orientation (deg)	Dim. Change (%)	Final Dim. Mm
3.1	A	8	32	-2.4541	**8.20**
	B	8	32	-2.4541	**8.20**
	C	10	58	-3.0186	**10.30**
	D	10	58	-3.0186	**10.30**
	E	12.81	97	-3.8653	**13.30**
	F	12.81	19	-2.1718	**13.08**
Section		Initial Dim (mm).	Orientation (deg)	Dim. Change (%)	Final Dim. (mm)
3.2	A	14.76	36	-2.5409	**15.14**
	B	14.76	36	-2.5409	**15.14**
	C	19.56	54	-2.9317	**20.13**
	D	19.56	54	-2.9317	**20.13**
	E	24.50	89	-3.6916	**25.41**
	F	24.50	17	-2.1284	**25.03**
Section		Initial Dim (mm).	Orientation (deg)	Dim. Change (%)	Final Dim. (mm)
3.3	A	16.92	35	-2.5192	**17.35**
	B	16.92	35	-2.5192	**17.35**
	C	19.56	55	-2.9534	**20.14**
	D	19.56	55	-2.9534	**20.14**
	E	25.86	84	-3.5831	**26.79**
	F	25.86	14	-2.0632	**26.40**
Section		Initial Dim (mm).	Orientation (deg)	Dim. Change (%)	Final Dim. (mm)
3.4	A	15.48	38	-2.5843	**15.88**
	B	15.48	38	-2.5843	**15.88**
	C	19.56	52	-2.8883	**20.12**
	D	19.56	52	-2.8883	**20.12**
	E	24.94	90	-3.7134	**25.87**
	F	24.94	14	-2.0632	**25.46**

Table 3 Table showing results for the data reported in Table 2

2.3 Interpretation of data and calculations

2.3.1 Equilibrium moisture content

In order to calculate the initial and final equilibrium moisture content (EMC) values by using the Excel software program, the following formula was used: [14]

$$EMC = \frac{1800}{W}\left[\frac{K.RH}{1-K.RH} + \frac{K_1K.RH + 2K_1K_2K^2RH^2}{1+K_1K.RH + K_1K^2RH^2}\right]$$

EMC	*equilibrium moisture content*
RH	*relative humidity (%/100)*
For temperature T in Celsius:	
W	$349 + 1.29T + 0.0135T^2$
K	$0.805 - 0.000736T - 0.00000273\,T^2$
K_1	$6.27 - 0.00938T - 0.000303\,T^2$
K_2	$1.91 + 0.0407T - 0.000293T^2$

2.3.2 Theoretical dimensional change

The following formula was used to establish the values for dimensional changes, that is, shrinkage or expansion: [15]

$$\Delta D = \frac{100(MC_i - MC_f)}{\frac{FSP}{S} - FSP + MC_i}$$

ΔD	*dimensional change*
D_i	*initial dimension*
MC_i	*initial moisture content (%)*
MC_f	*final moisture content (%)*
FSP	*fibre saturation point (%)*
S	*published value for shrinkage (%)*

[14] Forest Products Laboratory, (1999) 3-5.
[15] Hoadley, (1998) 12.

2.3.3 Linear dimensional change

Considering that all dimensions in every orientation would undergo radial contraction/expansion, the extent of tangential contraction/expansion needs to be found. The following formula was used to get the final increase/decrease for every recorded dimension:

Linear dimensional change

$$D_f = \frac{D_i}{100} \times 100 - \left[\left(\frac{V_t - V_r}{90} \times O^o \right) + V_r \right]$$

D_f	*final dimension*
D_i	*initial dimension*
V_t	*value for calculated tangential shrinkage (%)*
V_r	*value for calculated radial shrinkage(%)*
O^o	*orientation in degrees*

2.4 Reconstruction of the panel end grain presenting contraction/expansion and warping on AutoCAD

The results obtained by using the Microsoft Excel worksheets were transferred back onto AutoCAD. Figure 3 shows the steps required to build each element back using the predicted dimensions. The initial and final outline of the whole door width, i.e., boards 1, 2 and 3, can be viewed in Figure 4. Longitudinal contraction/shrinkage is insignificant, especially over short distances although it resulted to be still possible to predict it by this computer routine.

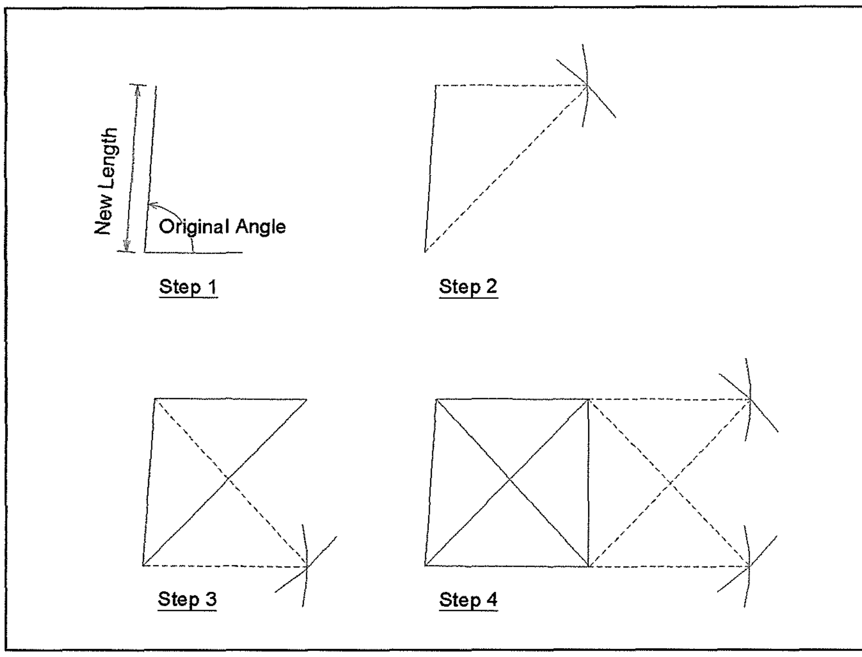

Figure 3 Procedure to reconstruct the elements using the predicted dimensions

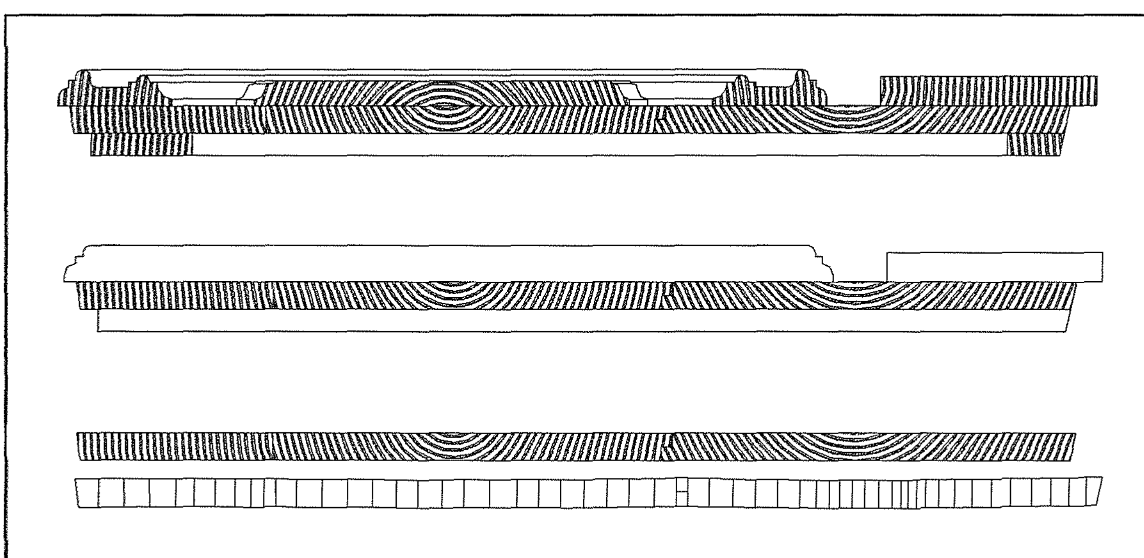

Figure 4 Top and centre: cross-sectional view of the sacristy door showing the frame, panel and mouldings attached to Boards 1, 2 and 3; Below: the boards before and after prediction, in this case showing expansion

2.5 Limitations of the computer analysis routine

It must be made clear that the calculations carried out by this computer routine are only approximations. Moreover, published data for wood shrinkage are just average values. The figures given are accountable to a large number of samples which individually may have a lot of anatomical differences resulting in different behavioural patterns. [Figure 5]

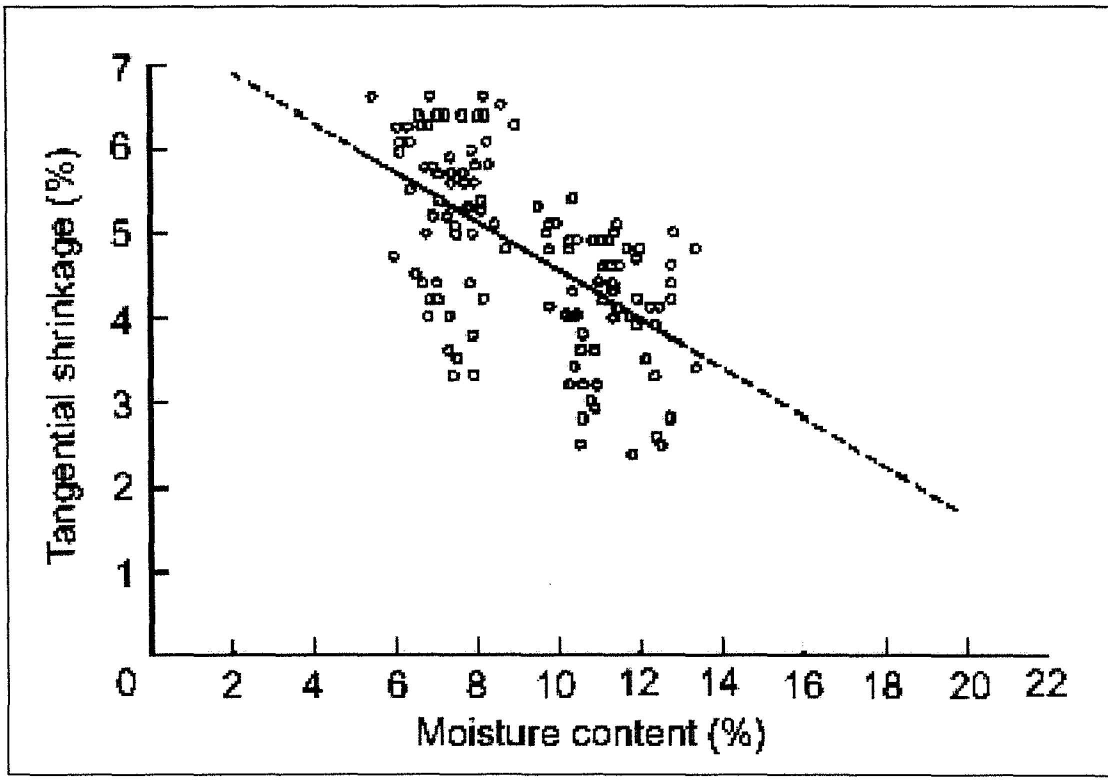

Figure 5 Variation in individual tangential shrinkage values of several Douglas-fir boards from one locality, dried from green state[16]

These predictions are only reliable under the following wood conditions:[17]

- Wood having cross grain: such a condition causes wood to shrink more in length and also leads to other types of warping like, for example, crook, bow, and twist
- Wood free from knots

[16] Forest Products Laboratory, (1999) 3-11.
[17] Formosa, (2003) 65.

- Compression wood, also responsible for twist, crook and bow
- Wood free from Tension wood
- Wood free from juvenile wood: according to the literature, wood from the centre of the tree (in some species) apart from being prone to structural failure, tends to shrink excessively lengthwise.[18]

Apart from satisfying the above conditioned, the panel should not be restricted by crossbars, frames and/or mounting hardware.[19] Varnish layers and preparation and painting layers, in the case of painted furniture, also lower the accuracy of results obtained from this computer analysis especially when cupping is evaluated. With time, the dimensional response of wood may diminish slightly due to decrease in hygroscopicity as well as the mechanical effects of repeated shrinkage/swelling cycles.[20]

2.6 Inherent and latent errors in the routine

As the grain orientation may change, adjacent sides of sections may not have the same dimensions. Such inaccuracy is negligible and not visible by the naked eye. This may be prevented by narrowing the sections and, therefore, the grain orientation would be more gradual.[21]

[18] Forest Products Laboratory (1999) 3-8.
[19] Both cases where the predictions were carried out, on the two sacristies considered in this study, there were restrictions.
[20] Dardes (1998) 18..
[21] Formosa, (2003) 66.

Appendix 4 – Glossary of technical and scientific terms in the study of wood

Angiosperms: Deciduous trees often referred to as hardwoods. In total about 30,000 angiosperm are known.[1] See also *Deciduous wood.*

Anisotropic: Wood behaves differently in all three directions. See also *Shrinking properties.*

Biseriate: In two rows.

Bordered pits: Circular connections between tracheids as well as between the ray tracheids; in the latter case, they are considerably smaller. From a radial section these connections look like two concentric circles.

Bound water: See *Fibre saturation point* and *Water in wood.*

Cellulose: Together with hemicellulose, they are the main constituents of the cell walls of wood. See also *Chemical composition of wood.*

Chemical composition of wood: Wood has a complex chemical composition. It is mainly composed of the elements carbon (C), oxygen (O), hydrogen (H), nitrogen (N) and minerals.[2] Cells are predominantly composed of cellulose, hemicelluloses and lignin. Table 1 indicates the major chemical components of wood.

MAJOR CHEMICAL COMPONENTS OF WOOD	
COMPONENT	**%**
CELLULOSE	40 – 50
HEMICELLULOSE	20 – 30
LIGNIN	25 – 30
ASH	0.1 – 0.5
EXTRACTIVES	1 – 5

Table 1 The major components of wood[3]

[1] Larsen (2000) 25.
[2] Nicolaus, (1999) 17.
[3] Table adapted from Formosa, (2003) 17.

The repeating unit in cellulose is $C_6H_{10}O_5$, called *glucose anhydride.* Figure 1 shows the polymeric cellulose structure.

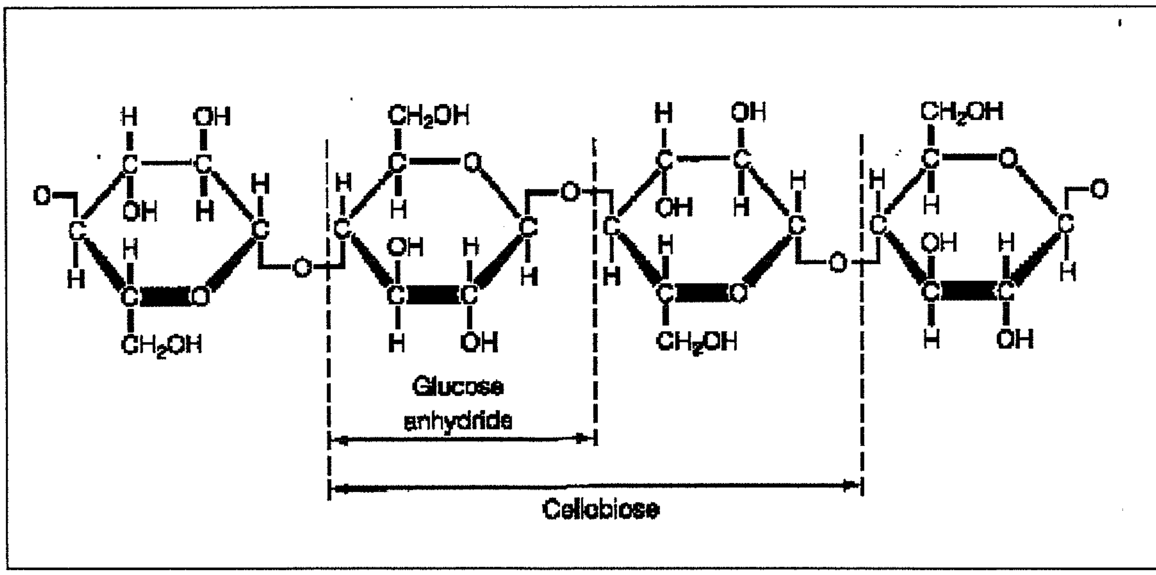

Figure 1 The structure of cellulose[4]

The average degree of polymerisation for cellulose is about 10,000, while there are 150 to 200 of hemicelluloses. Cellulose is responsible for the tensile strength of wood. The function of hemicelluloses has not yet been fully understood but it is thought that it plays an important role in the expansion and contraction process.[5]

Coniferous Wood: This wood originates from gymnosperms that are composed of longitudinal tracheids varying from 2 to 6 mm in length. [Figure 2] The width of these tracheids is approximately 1/100 their length (20– 60µm).

[4] Hoadley, (1998) 9.
[5] Nicolaus, (1999) 17.

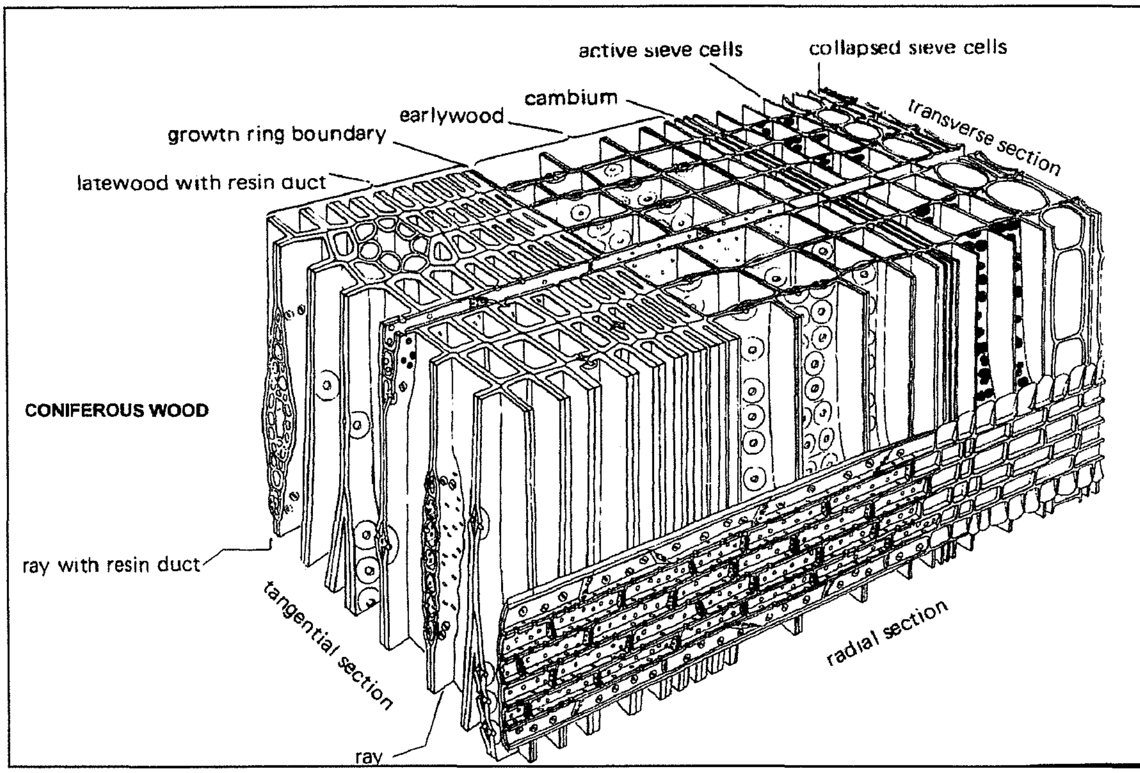

Figure 2 The microscopic structure of coniferous wood[6]

Ray parenchyma, responsible for the horizontal means of transportation, is present in all gymnosperms while vertical parenchyma, used for storage, can also be found in some other species. In some types of wood each group of ray parenchyma are covered by ray tracheids.

All gymnosperms have uniseriate horizontal ray parenchyma while some other species also have them in the longitudinal direction. Some gymnosperms have longitudinal and horizontal resin canals. The latter are often referred to as *fusiform* rays. [Figure 2] Latewood cells, unlike cells in earlywood, are flattened and also have thicker cell walls. Growth rings are visible in most species. The width of each ring depends on periodic climatic changes.

Crossfield pits: Openings between ray parenchyma and tracheids.

Deciduous wood: The term deciduous is often misleading since it actually means that tree loses its leaves at wintertime which is not always the case. This wood

[6] Schweingruber, (1990) 16.

originates from angiosperms (*hardwoods*). Angiosperms are more complex than gymnosperms since their longitudinal formation consists of vessels of large diameter, tracheids, parenchyma and fibres. [Figure 3]

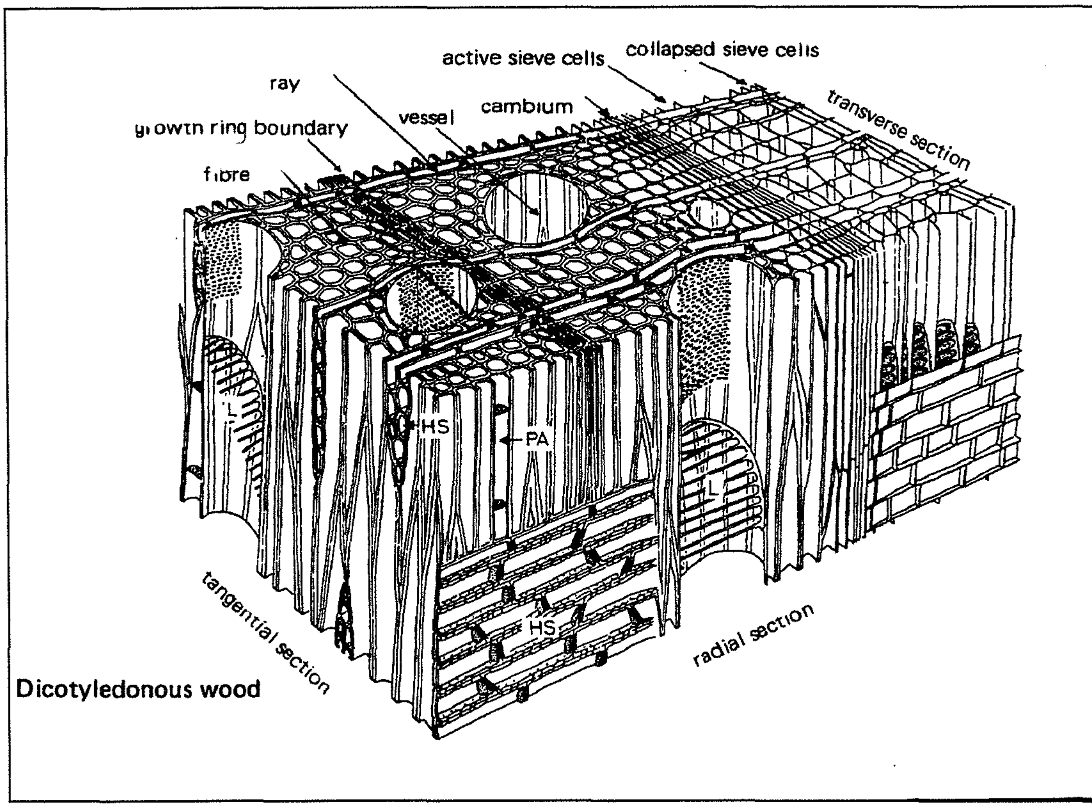

Figure 3 The microscopic structure of deciduous wood[7]

Parenchyma rays run horizontally, although in some species they also run vertically and serve for storage. Horizontal parenchyma rays offer a weak point, especially when multiseriate (more than a single row) and present in great widths such as in *Quercus sp.* (oak). Vessel elements have a thin wall with respect to their relatively large diameter. They loose their end walls, referred to as perforation plates, to form one continuous conducting pipe. When pores are concentrated in the early wood, it is called ring-porous, while if they are distributed all over without a distinct pattern, the wood is of the diffuse-porous type. (Figures 4 and 5)[8] At times, when the above pore layouts are both evident, the wood would be semi-diffuse (or semi-ring) porous.

[7] Schweingruber, (1990) 16.

[8] Pores is another term for vessels, used mainly for vessels that are observed in transverse section.

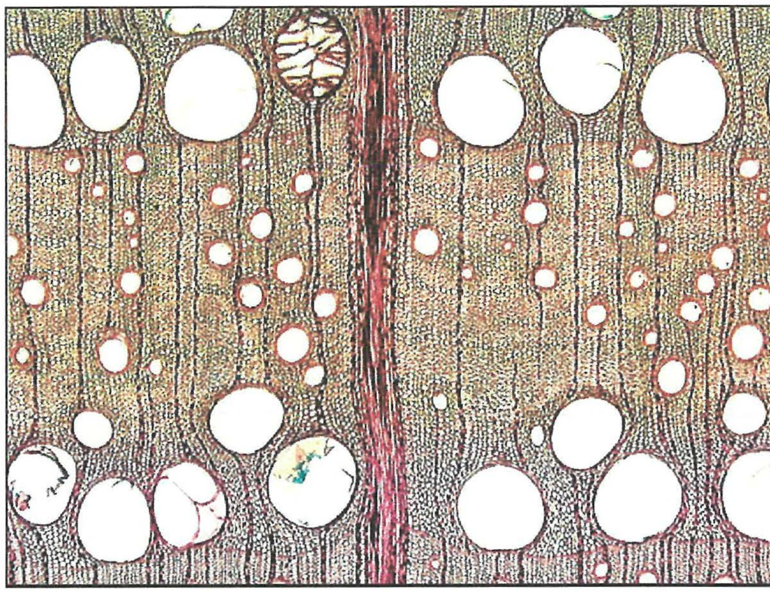

Figure 4 Transverse section of a ring porous wood – *Quercus spp.* (red oak)[9]

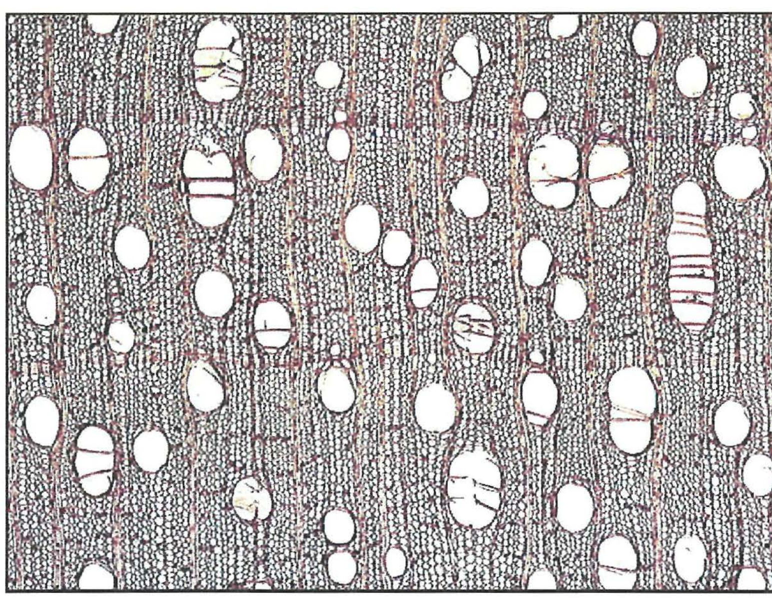

Figure 5 Transverse section of a diffuse porous wood *Juglans regia* L. (walnut)[10]

Diffuse-porous: See *Deciduous wood.*

Earlywood: Springwood.

Equilibrium moisture content (EMC): Wood adsorbs and desorbs water and eventually reaches the equilibrium moisture content (EMC) with the surrounding atmosphere. Figure 6 shows the relationship between RH and EMC. In this example,

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[9] Richter, (2000) CD-ROM.
[10] Ibid.

the fibre saturation point (FSP) is indicated at 30%; note that this value is different for different types of wood. For example, in *Dalbergia sp.* (rosewood) it can only reach a value of 22 to 24%, while with *Betula spp.* (birch) and *Fagus sylvatica* L. (beech) it may be as high as 32 to 34%.

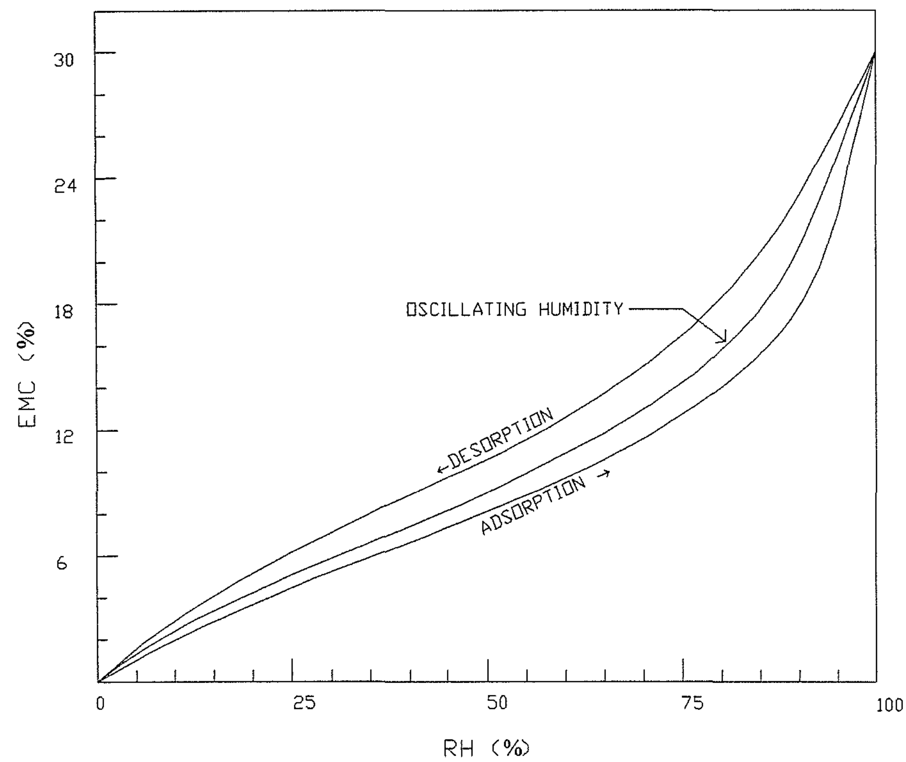

Figure 6 Relationship between RH and EMC in Picea sp. (spruce) at a temperature of 21°C[11]

On plotting RH against EMC, as in Figure 6, a hysterisis is clearly present. Wood loosing moisture would have a higher MC than a wood under adsorption at the same relative humidity (RH) and temperature (T) levels. For a rise of 14 to 16°C, there will be an approximate decrease of 1% in MC.

Wood is always exposed to both long-term (seasonal) and short-term (daily) changes in both RH and T of the environment. Wood is therefore always undergoing, at least, slight changes in MC. Such changes are usually gradual, and short-term fluctuations

[11] Hoadley, (1998) 13

tend to affect the surface of the wood only. MC variations cannot be totally prevented, not even by paints or varnishes, although the process is retarded.[12]

The relationship between EMC, RH and T is presented in the following formula:

Equilibrium moisture content[13]

$$EMC = \frac{1800}{W}\left[\frac{K.RH}{1-K.RH} + \frac{K_1K.RH + 2K_1K_2K^2RH^2}{1+K_1K.RH + K_1K^2RH^2}\right]$$

EMC	*equilibrium moisture content*
RH	*relative humidity (%/100)*
For temperature T in Celsius	
W	$349 + 1.29T + 0.0135T^2$
K	$0.805 - 0.000736T - 0.00000273\ T^2$
K_1	$6.27 - 0.00938T - 0.000303\ T^2$
K_2	$1.91 + 0.0407T - 0.000293T^2$

The relationship between RH, T and EMC is presented graphically in Figure 7. In this plot, the red lines indicate ambient conditions for a temperature of 35°C and an RH of 53%, which results in a MC of about 8.75%. In the second example, marked by green lines, the T is lower at 16°C and the RH higher at 69%, giving a MC of about 12.75%. This method is only approximate. In fact, if these figures are used in the EMC formula, MC values of 9.25% and 13.02% respectively are obtained.[14]

[12] Forest Products Laboratory, (1999) 3-5.
[13] Ibid.
[14] Formosa, (2003) 28.

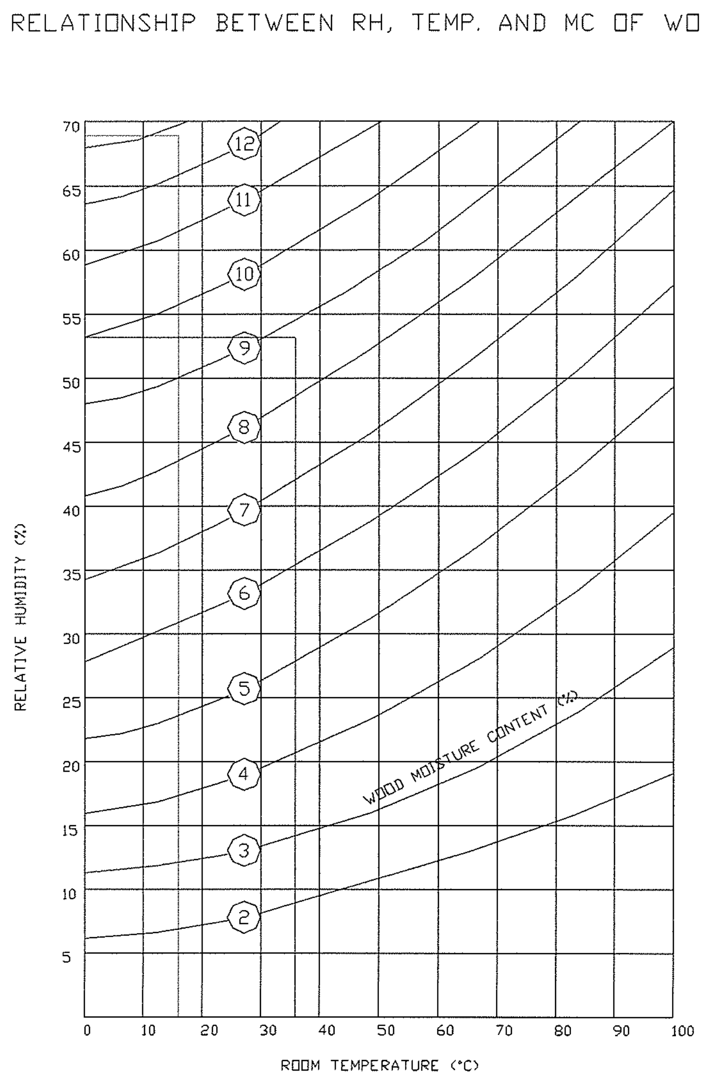

Figure 7 Graphical representation of the relationship between ambient temperature, relative humidity and wood moisture content[15]

See also *Moisture Content.*

Estimating dimensional change: Since percentage shrinkage and MC are only estimated, expected dimensional change cannot be calculated precisely. When the wood is in its green state, or else above FSP and dried to a specific MC, the linear decrease in dimension can be calculated from the following relationship:[16]

[15] Graph adapted from Nicolaus, (1999) 20.
[16] Formosa, (2003) 36.

$$S_m = S_o\left(\frac{30 - MC}{30}\right)$$

S_m	*shrinkage (%) from green condition to MC <30%*
S_o	*shrinkage coefficient for radial, tangential or volumetric*

For higher accuracy, the test sample of wood should be free from knots as much as possible. Reaction wood changes shrinking and warping properties considerably. The wood should not be restricted like in the case of fixed horizontal parts. Surface coatings also lessen the accuracy of the results. Published literature data for the coefficient of shrinkage (tangential, radial and longitudinal) as well as FSP are all average values which might differ a lot in reality. Studies on *Pseudotsuga menziesii* (Douglas fir) boards coming from the same locality showed great variation in tangential shrinkage as shown in Figure 8.[17]

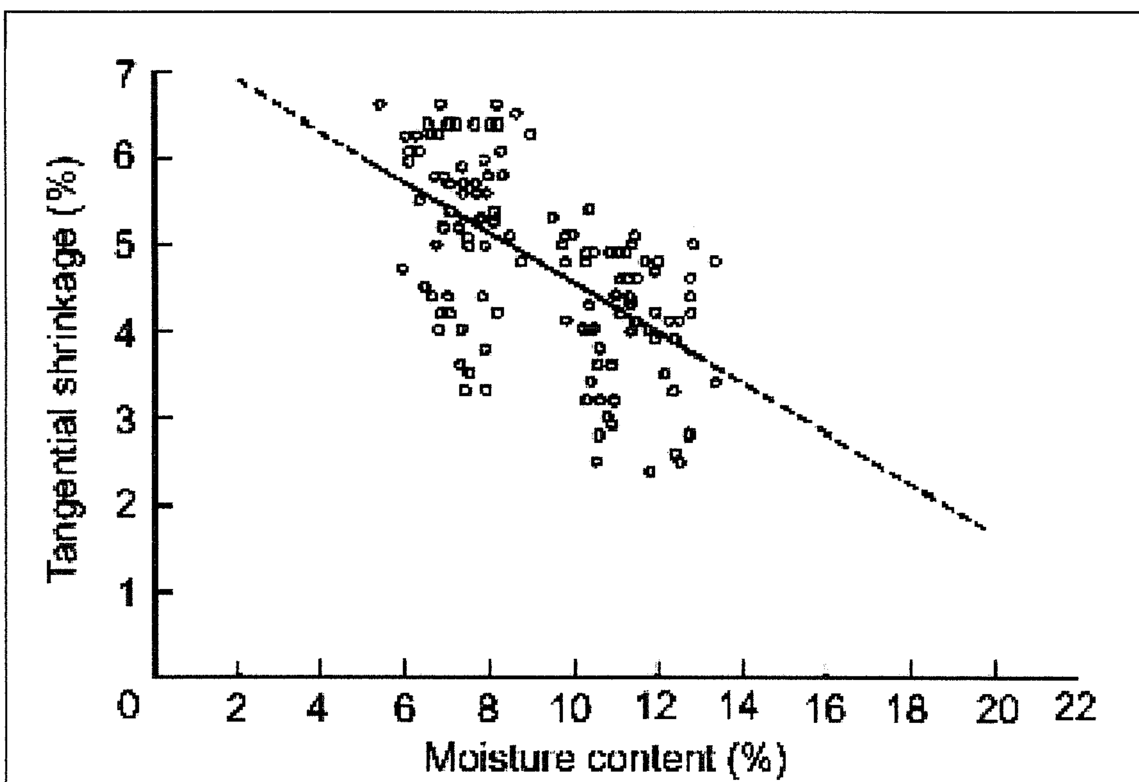

Figure 8 Variation in individual tangential shrinkage values of several Douglas fir boards from one locality, dried from green condition[18]

[17] Forest Products Laboratory, (1999) 3-11.
[18] Ibid.

With time, the dimensional response of wood may become slightly lower due to the decrease of hygroscopicity as well as mechanical effects of repeated shrinkage/swelling cycles[19].

See also *Shrinkage properties, Theoretical dimensional change* and *Graphical dimensional change*.

Extractives: Also referred to as secondary metabolites. They, associated with the formation of heartwood in trees, are low molecular weight components such as tannins, resin acids, fats, waxes and carbohydrates. When they are extracted, little change to the wood structure occurs. Apart from giving colour to wood, in some species, they serve as a natural resistance against decay due to the toxic component compounds.[20]

Fenestriform: Window-like type of aperture between ray parenchyma and tracheids in gymnosperms.

Fibres: See *Deciduous wood.*

Fibre saturation point (FSP): It is the maximum amount of water, expressed as a percentage, that wood can adsorb and is held by hydrogen bonding and all other forms of adsorption. See also *Water in wood.*

Free water: Free water in wood cells, following fibre saturation point (FSP). See also *Fibre saturation point* and *Water in wood.*

Fusiform rays: See *Coniferous wood.*

Graphic dimensional change: This is a less accurate method to predict linear dimensional changes. [Figure 9]

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[19] Hoadley, (1998) 18.
[20] Ibid., 10.

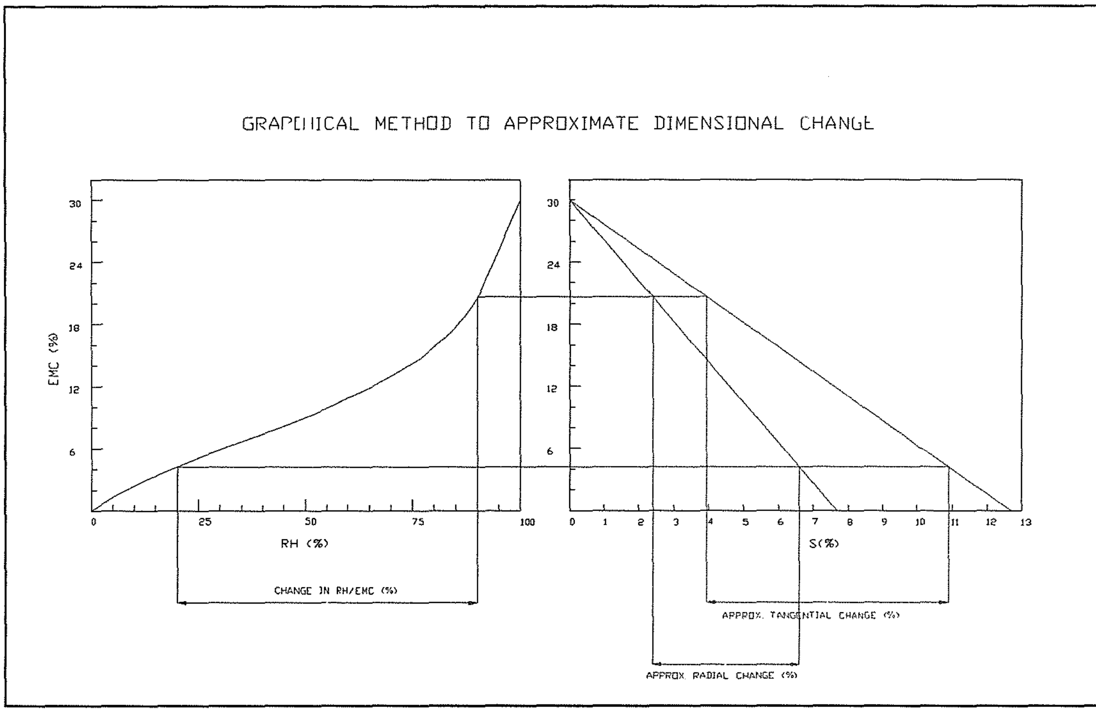

Figure 9 Graphical method to predict shrinkage[21]

In the example shown above, Hickory (Shellbark) was used. For a tangential shrinkage of 12.6% and a radial shrinkage of 7.6%,[22] when the RH increased from 20% to 90% there is a tangential increase of approx. 6.9% and a corresponding radial expansion of approximately 4.5%.

See also *Estimated dimensional change.*

Green wood: Freshly cut wood. See also *Moisture content.*

Growth ring boundaries: The distinction between latewood and the new earlywood.

Gymnosperms: Coniferous trees often referred to as softwoods. In total about 520 gymnosperm tree species are known. [23] See also *Coniferous wood.*

[21] Graph adapted from Hoadley, (1998) 17.
[22] Forest Products Laboratory, (1999) 3-9.
[23] Larsen (2000) 25.

Hardwood: Wood from deciduous trees. This term is often misleading; *Ochroma sp.* (balsa wood), being a hardwood, has a SG of 0.15, while *Taxus sp.* (yew), a softwood, has a SG of 0.65. See also *Deciduous wood.*

Heartwood: The inner part of the tree where the cells have died and serve as a storage for extractives. Hardwood is normally harder, less permeable, heavier and more durable than sapwood. See also *Sapwood* and *Moisture content.*

Helical thickening: Spiral, lignified matter in tracheides, in gymnosperms, or vessels and fibres in angiosperms. [Figure 10]

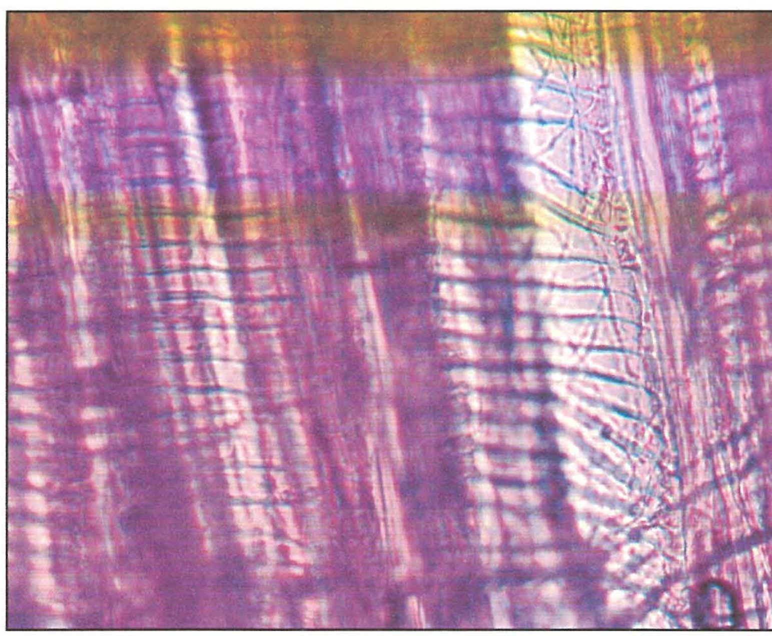

Figure 10 Helical thickening observed in a Pseutodsuga menziesii (douglas fir) sample[24]

Hemicellulose: See *Cellulose* and *Chemical composition of wood.*

Heterocellular rays: Two different layouts of ray parenchyma (in angiosperms). [Figure 11]

[24] This sample derived from one of the mouldings of the sacristy of St Paul's church in Valletta.

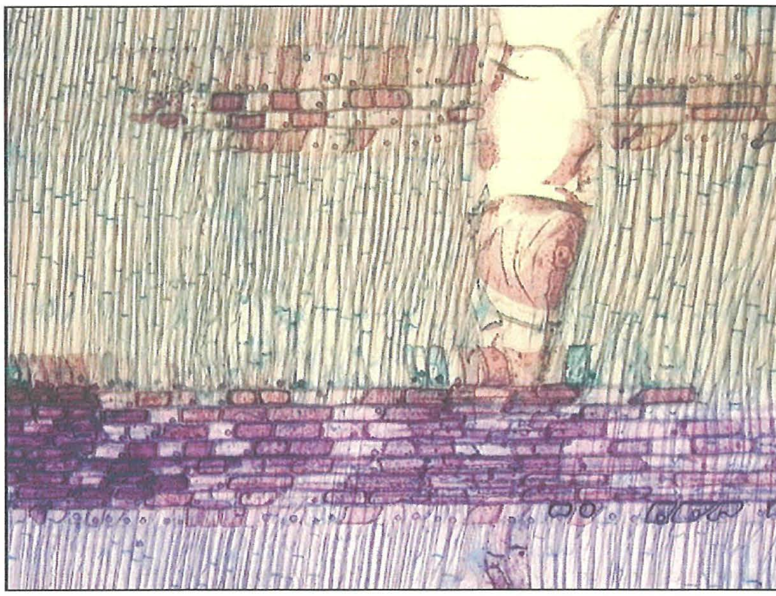

Figure 11 Radial section showing heterocellular type of ray parenchyma – *Aucoumea klaineana* Pierre (gaboon)[25]

Homocellular rays: Ray parenchyma having the same layout (in angiosperms).

Intervessel pits: Apertures between vessels and the surrounding cells. These could be scalariform, alternate or opposite. [Figure 12]

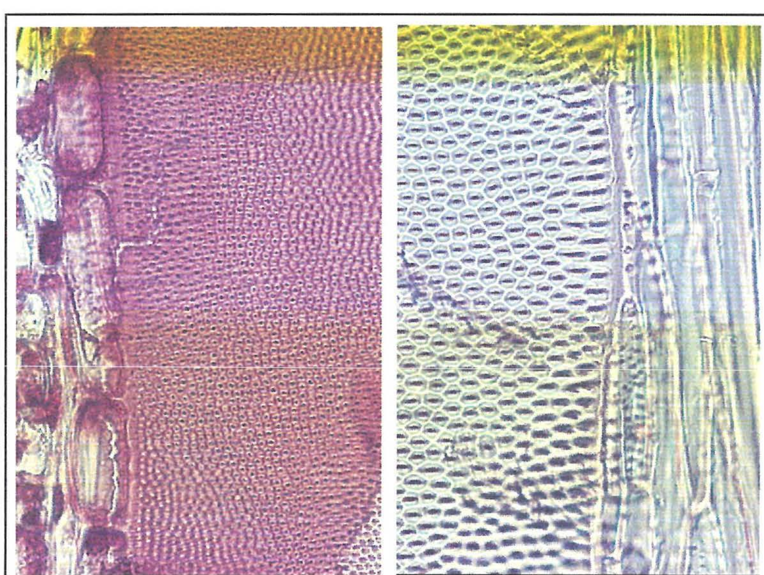

Figure 12 Alternate intervessel pits –left; *Swietenia macrophylla* (mahogany), right; *Brosimopsis oblonga*[26]

Latewood: Summer-autumn wood.

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[25] Richter, (2000) CD-ROM.
[26] Ibid.

Lignin: Being one of the main constituent materials of wood cells, it is about 25 to 30% of the main part of wood and has hardening and binding properties. Lignin is a complex three-dimensional structure that stiffens the cell wall and therefore enhances the compressive strength of wood. See also *Chemical composition of wood.*

Maximum moisture content: The maximum moisture content of every type of wood can be calculated by the following formula: [27]

$$M_{\max} = 100\left(\frac{1.54 - G_b}{1.54 \times G_b}\right)$$

M_{max}	*maximum moisture content (%)*
G_b	*basic specific gravity (based on oven dry weight and green volume)[28]*
Note	*1.54 is the specific gravity of wood cell walls*

By changing the subject in the above formula one can arrive at the specific gravity (SG) of a piece of wood which contains the maximum moisture content:

$$G_b = \frac{154}{(1.54 M_{\max}) + 100}$$

All wood may sink since cell wall SG is above 1, and specifically 1.54. The following formula can be used to calculate the MC at which wood will sink: [29]

$$M_{\sin k} = \frac{100(1 - G_b)}{G_b}$$

M_{sink}	*maximum moisture content at which wood sinks (%)*

See also *Moisture Content.*

[27] Forest Products Laboratory, (1999) 3-5.
[28] Green wood may be also referred to as wet or freshly cut wood.
[29] Forest Products Laboratory, (1999) 3-5.

Microscopic structure of wood: Figure 13 represents a typical softwood tracheid. S_1, S_2, and S_3 indicate the secondary cell wall. The striations can only be seen under an electron microscope. S_1 and S_3 are nearly perpendicular to the cell axis while fibrils in S_2 are almost parallel. Water molecules cannot penetrate the crystallites but it can be adsorbed by hydrogen bonding in one or more layers.

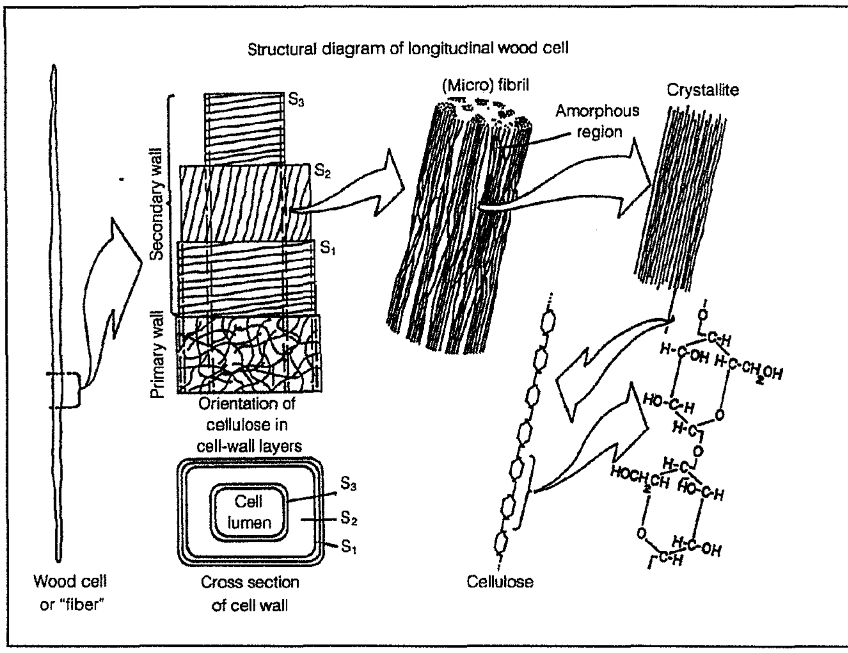

Figure 13 Structural diagram of a longitudinal tracheid[30]

Moisture content (MC): The amount of water in wood expressed as a percentage with respect to (oven) dry wood. The formula is as follows:

$$MC = \frac{W_w - D_w}{D_w} \times 100$$

MC	*moisture content (%)*
W_w	*wet weight*
D_w	*dry weight*

An oven is needed to dry wood completely (0% MC) and the temperature should be set at 100° to 105° C.[31]

[30] Larsen (2000) 25.

When wood is in the green state, it exceeds FSP and MC varies from 31% (Pine, Longleaf) to 162% (Cottonwood) depending on the density of the wood. [32]

There is a big variation in the MC of green wood between heartwood and sapwood of the same species, e.g., in incense cedar, the heartwood might have 40% MC while sapwood would reach a MC of 213%.[33] Some species have low amounts of sapwood, e.g., the larch (*Larix sp.*) shown in Plate 1. When the cells of sapwood die off, conduction through such cells will cease and the new heartwood layer is formed.[34] Heartwood, even when it cannot be distinguished from sapwood, would still be present.

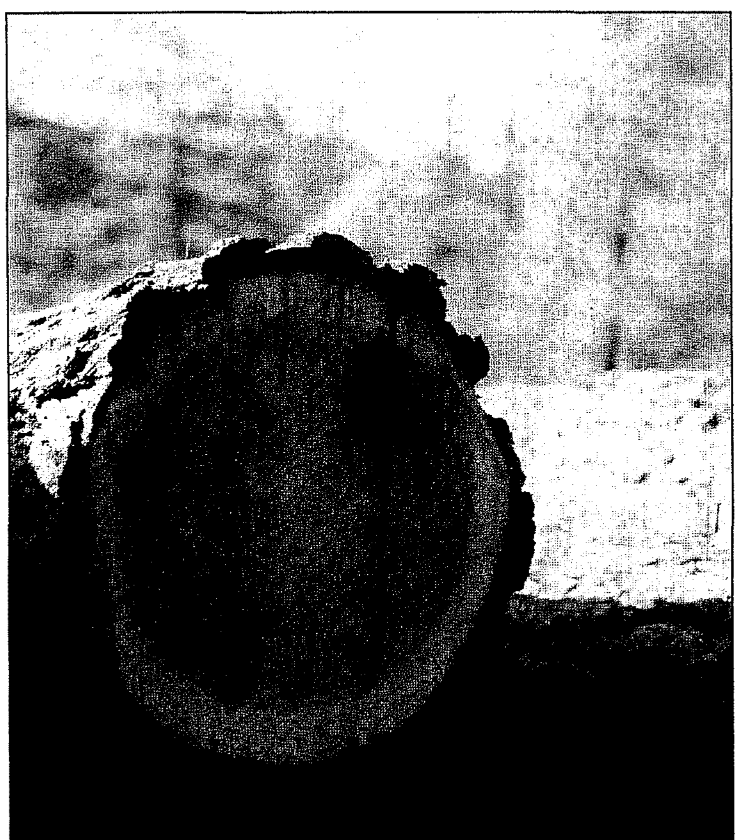

Plate 1 End section of a *Larix decidua* log (larch)[35]

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[31] Hoadley, (1998) 12.
[32] Forest Products Laboratory, (1999) 3-6.
[33] Ibid.
[34] Larsen, (2000) 96.
[35] Ibid., 98.

See also *Water in wood.*

Multiseriate: More than a single row of ray cells. [Figure 14] See also *Deciduous wood* and *Parenchyma rays.*

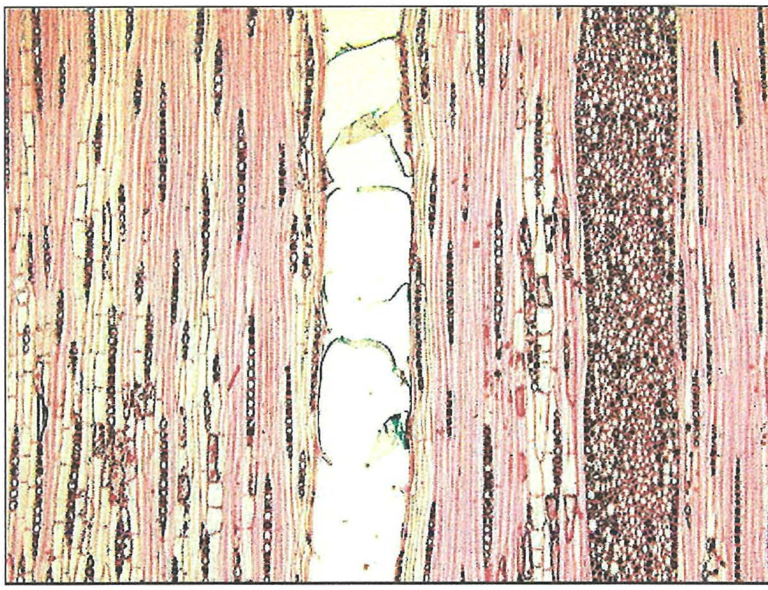

Figure 14 Tangential section showing multiseriate ray parenchyma in an angiosperm – *Quercus spp.* (red oak)[36]

Parenchyma rays: Wood cells in the horizontal direction. In most angiosperms and some gymnosperms they are also located vertically, referred to as axial parenchyma. In angiosperms it may be uniseriate and/or multiseriate. See also *Multiseriate, Coniferous wood* and *Deciduous wood.*

Perforation plates: End walls of vessels. These are mostly of the simple, scalariform or reticulate type. [Figure 15] See also *Deciduous wood.*

[36] Richter, (2000) CD-ROM.

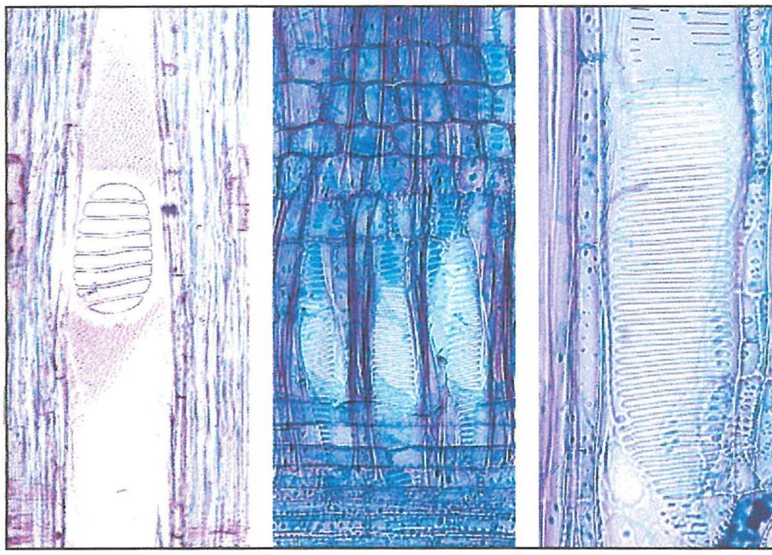

Figure 15 Three views of scalariform perforation plates – left, *Dialyanthera gracilipes*; middle, *Laurelia nova-zelandica*; right, *Turpinia sphaerocarpa*[37]

Pores: The main type of cell found in deciduous types of wood. See also *Vessels* and *Deciduous wood.*

Ray parenchyma: See *Parenchyma rays, Coniferous wood* and *Deciduous wood.*

Ray tracheids: These are horizontal types of cells which surround the radial ray parenchyma in gymnosperms of certain species. The type of cell wall, whether dentate, smooth, wavy, etc., may determine one type of genera from another.

Relative humidity (RH): The amount of water the air contains, expressed as a percentage of the total amount of water the air can hold at a specific temperature. See also *Equilibrium moisture content.*

Resin canals: See *Coniferous wood.*

Restrained expansion and contraction: When wood is mechanically restrained, it will be under tension during drying and under compression if it is gaining moisture. The elastic limit of wood under compression or tension is approximately 0.5 to 1%.[38] Beyond this elastic limit, wood will enter in the plastic region and it will suffer

[37] Richter, (2000) CD-ROM.
[38] Hoadley, (1998) 18.

permanent deformation. During the elastic phase, crystalline elements behave rigid and amorphous parts viscoplastically. Beyond the elastic region, the wood cells suffer microscopic fractures; such activity is irreversible and wood enters the plastic region as illustrated in Figure 16.[39]

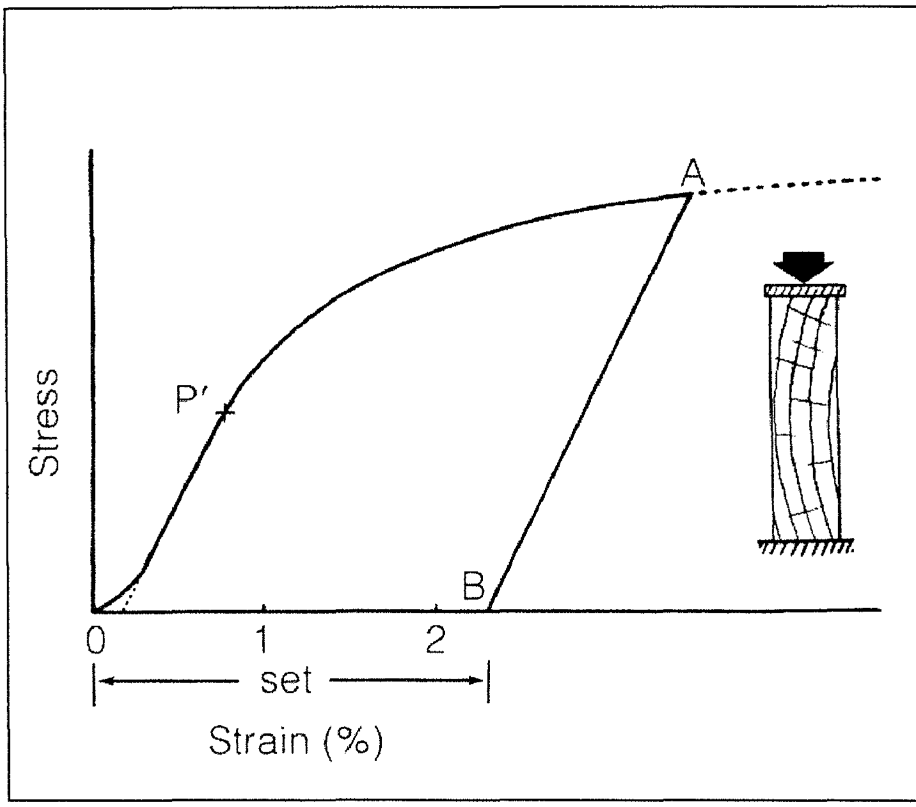

Figure 16 Stress-strain relationship plotted for a wooden block under compression beyond its elastic limit P' to point A[40]

Let us consider an unrestricted panel whose MC is increased and as a result of such an increase, it will experience a total linear increase of, say, x%. If said panel, e.g., a door panel, is restricted by horizontal parts and the same conditions of MC are applied, the first 1% will be in the elastic region while the rest (i.e., (x-1)%) of this increase would be plastic deformation.

When the original MC is reached again, the panel will crack and such cracks will be approximately (x – 1)% of the restricted length[41], due to plastic deformation. If on the other hand the restricted panel is put in a drier condition where it shrinks

[39] Nicolaus, (1999) 23.
[40] Hoadley, (1998) 18.
[41] This distance usually refers to the distance/s between nails.

dimensionally by x%, the wood will go through the 1% elastic limit and the rest through plastic deformation, but, wood will give way and split after 1.5% tensile shrinkage. When the wood is back to the original MC, the gap of the crack will close. Figure 17 illustrates this example. When a panel has suffered a compression, it cannot be reverted to its initial state by restraining its shrinkage due to the limit in tensile strain of about 1.5%.

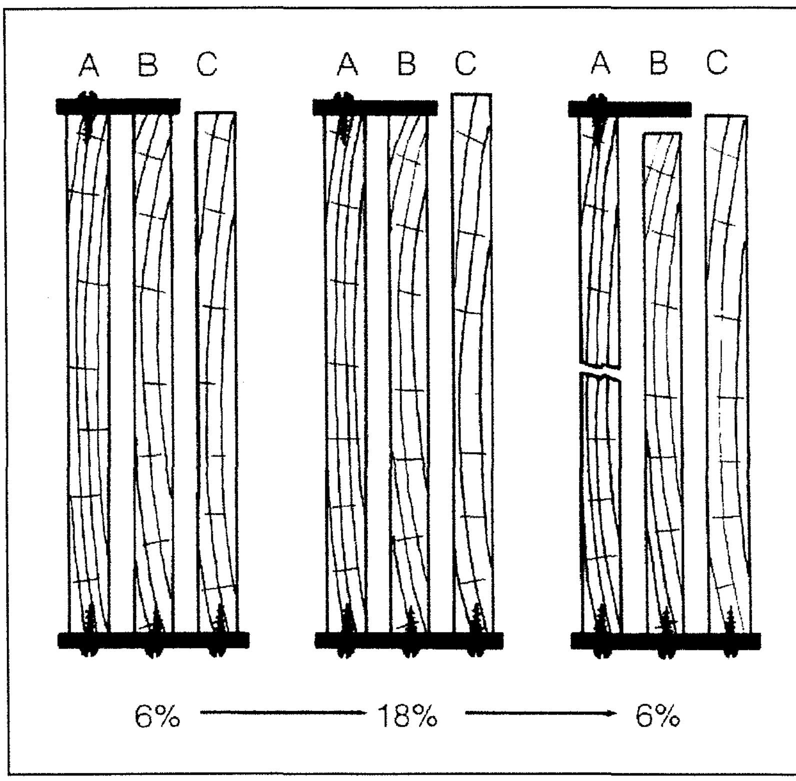

Figure 17 An example illustrating restrained swelling[42]

Ring porous: See *Deciduous wood.*

Sapwood: It is composed of the outer layers of conductive wood cells found in the outer part of a tree trunk. See also *Heartwood* and *Moisture content.*

Softwood: Wood coming from coniferous trees. The term is often misleading. See also *Hardwood* and *Coniferous wood.*

Semi-ring-porous: See *Deciduous wood.*

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[42] Hoadley, (1998) 19.

Shrinkage properties: Wood is anisotropic, i.e., it exhibits different values for the same property measured in different directions. Published values for shrinkage indicate the dimensional change from green state[43] till oven dry expressed as a percentage. Linear values are indicated for each particular direction as follows:

S_l – longitudinal shrinkage: along the fibres

S_t – tangential shrinkage: along the growth rings

S_r – radial shrinkage: along the parenchyma rays (refer to Figure 21)

Tangential and radial shrinkage values vary considerably between different types of wood, but, in general, the former results to be about twice radial shrinkage. Table 2 shows the radial and tangential values of some of the woods analysed from the sacristies.

COMMON NAME	SCIENTIFIC NAME	SHRINKAGE % (FROM GREEN STATE TILL OVEN DRY)	
		TANGENTIAL	RADIAL
Coniferous wood			
Spruce	*Picea sp.*	7.4	3.6
Fir	*Abies sp.*	7.6	3.8
Scots pine	*Pinus sylvestris*	7.7	4
Larch	*Larix decidua*	7.8	3.3
Deciduous wood			
Walnut (European)	*Juglans regia*	6.4	4.3
Chestnut	*Castanea sp.*	6.8	4.0
Cherry	*Prunus sp.*	7.8	4.2
Maple	*Acer sp.*	8.8	4.2
Lime	*Tilia sp.*	9.5	6.8

Table 2 Estimated values for tangential and radial shrinkage of some woods analysed in this study[44]

Longitudinal shrinkage is quite minimal and is normally between 0.1 to 0.2%. In juvenile wood, reaction wood or short grained wood, such values could be larger by

[43] Green wood is always above FSP but dimensional change would not take place above FSP.
[44] Table adapted from Hoadley, (1998) 15.

ten or twenty times than normal. Shrinkage is approximately proportional to MC change, as shown in Figure 18.

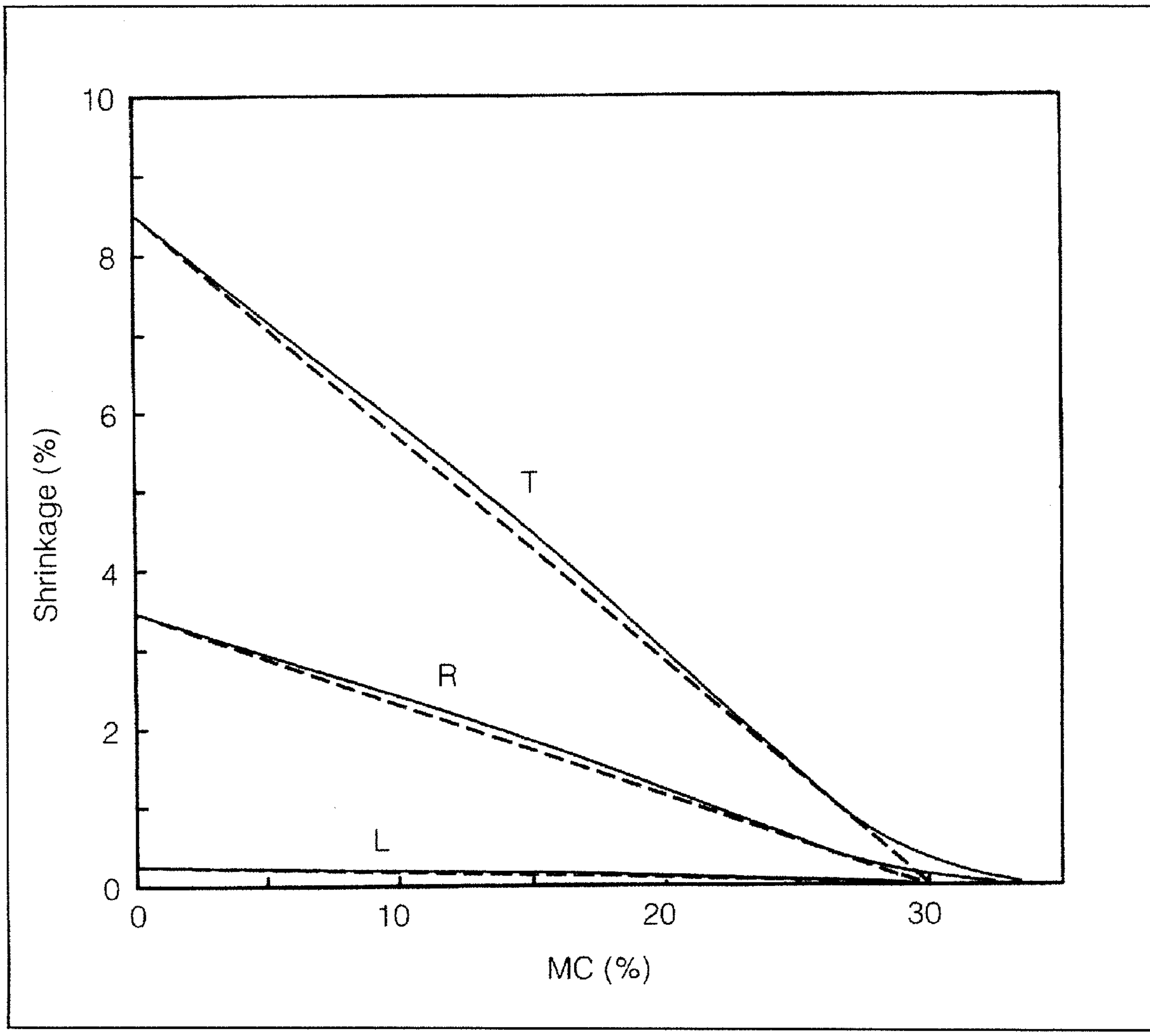

Figure 18 Relationship between shrinkage and wood moisture content[45]

The lower the difference between tangential and radial shrinkage coefficients, and the less the sum of the three coefficients of shrinkage, the more durable the wood is.[46]

Table 3 represents the percentage contraction q (both the radial movement q_r and the tangential movement q_t) of some woods found in the sacristies.

[45] Hoardley, (1998) 15.
[46] Nicolaus, (1999) 21.

PERCENTAGE MOVEMENT (q) IN %		
TYPE OF WOOD	q_r	q_t
Tilia sp. (lime)	0.23	0.30
Juglans regia(walnut)	0.18	0.29
Pinus sp. (Pine)	0.19	0.36
Picea sp. (spruce)	0.19	0.39
q_r – Radial movement, q_t – Tangential movement Figures refer to a reduction in wood MC of 1%.		

Table 3 Percentage movement of some woods analysed in this study[47]

For example, if a tangentially cut *Picea sp.* door panel has a 4% MC decrease and its width is 500mm, then:

$$Shrinkage = \frac{500mm \times 4 \times 0.39}{100}$$
$$Shrinkage = 7.8mm$$

Specific gravity (SG): Also referred to as relative density. It is an essential indicator of the properties of wood. Woods with high SG usually contract and expand more than woods with lower values. See also *Maximum moisture content.*

Theoretical dimensional change. Another way to calculate dimensional change. The formula below can be used to predict dimensional change, knowing the initial and final levels of MC: [48]

$$\Delta D = \frac{D_i(MC_i - MC_f)}{\frac{FSP}{S} - FSP + MC_i}$$

[47] Table adapted from Nicolaus, (1999) 21.
[48] Hoadley, (1998) 12.

ΔD	*dimensional change*
D_i	*initial dimension*
MC_i	*initial moisture content (%)*
MC_f	*final moisture content (%)*
FSP	*fibre saturation point (%)*
S	*published value for shrinkage (%)*

The above formula is theoretical and is just an approximation. Hoadley states that it is only ±25% effective. [49]

See also *Estimating dimensional change, Shrinkage properties and Graphical dimensional change.*

Thermal expansion of wood: Temperature as an isolated variable influences the strength of wood; its strength decreases as temperature increases. Thermal expansion of wood, equivalent to about 1/3 that of steel, is negligible.[50] This effect is mostly pronounced at higher wood MC. When temperature increases, wood looses moisture and shrinks and such minimal thermal expansion is overcome. Table 4 shows different thermal expansion coefficients for different materials.

THERMAL EXPANSION COEFFICIENTS OF SOME MATERIALS	
MATERIAL	**mm per °C**
CONCRETE	$10*10^{-6}$
LIMESTONE	$7*10^{-6}$
GLASS (10% ALKALI)	$4.8*10^{-6}$
STEEL	$10 \div 14*10^{-6}$
ALUMINIUM	$23.8*10^{-6}$
PINE - ALONG FIBRES	$5.4*10^{-6}$
PINE - ACROSS FIBRES	$34.1*10^{-6}$
OAK – ALONG FIBRES	$3.4*10^{-6}$
OAK – ACROSS FIBRES	$28.4*10^{-6}$
FIR – ACROSS FIBRES	$58.4*10^{-6}$
WOOD LAMINATES	$10 \div 40*10^{-6}$
POLYESTER RESINS	$100 \div 150*10^{-6}$
EPOXY RESINS	$60*10^{-6}$

Table 4 Thermal expansion coefficients of materials used in buildings[51]

[49] Hoadley, (1998) 12.
[50] Torraca, (1982) 37.
[51] Table adapted from Torraca, (1982) 37.

Although figures for wood are low, it does not mean that variations in temperature will not affect a piece of furniture. There are other constituent materials that may undergo deformation and/or degradation when exposed to temperature variations. These may include textiles used as upholstery, glues and surface coatings. Problems arise with *boule* furniture since the inlayed metals will expand while the wood contracts.

Tracheides: Wood cells abundantly found in conifers. They also occur in some deciduous trees in conjunction with fibres.[52] See also *Coniferous wood* and *Deciduous wood.*

Uniseriate: Single row.

Vessels: Main type of cell found in deciduous types of wood. See also *Deciduous wood.*

Warping: Although dimensional change alone may be a serious consequence of moisture variation, even minor amounts of uneven shrinkage or swelling can cause warp, i.e., the distortion of wood from its desired or intended shape. [Figure 19] The four main types of distortions are:

- Cup: deviation from flatness across the width of the board
- Twist: situation in which four corners of a flat face do not lie in the same plane
- Bow: deviation from lengthwise flatness of a board
- Crook: departure from end-to-end straightness along the edge of a board

[52] Corkhill, (1984) 591.

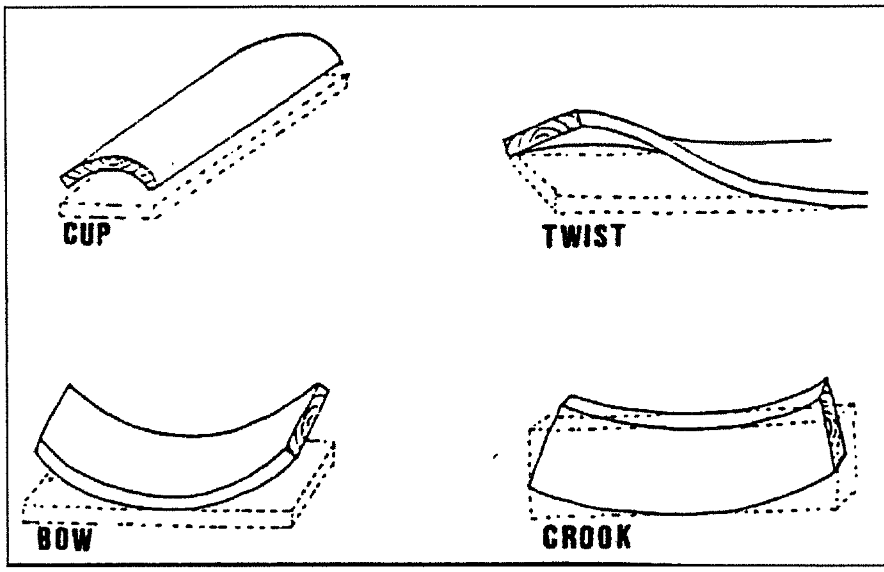

Figure 19 Different types of warping[53]

Cupping is the most commonly found type of warp in wide boards having a tangential grain orientation. Figure 20 shows different types of board positions in a *through and through* type of conversion.

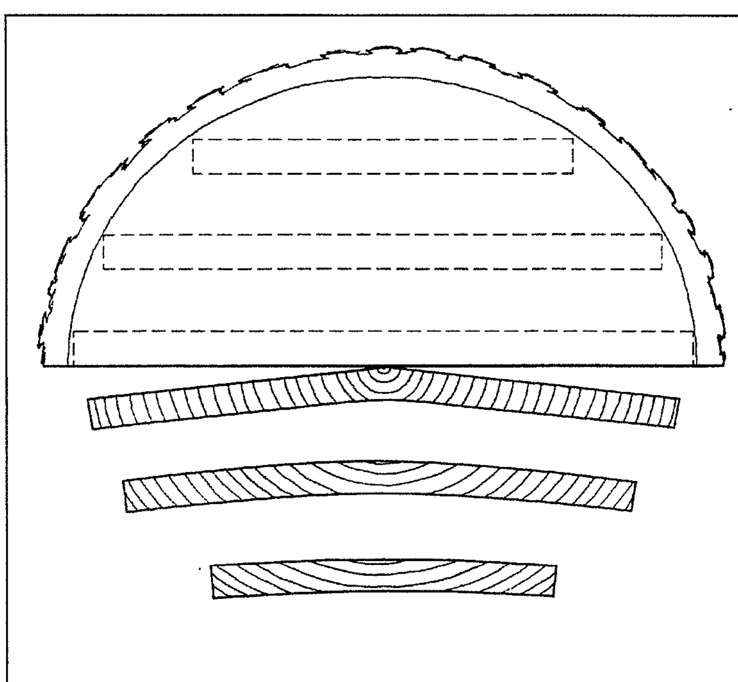

Figure 20 Cupping due to tangential orientation of the grain[54]

[53] Formosa, (2003) 41.
[54] Hoardley, (1998) 19.

Under normal conditions, radial cut boards, unlike tangentially cut boards, are not supposed to cup. Boards that are secured flat may crack along the grain if normal cupping is prevented. This may be the result in parts of furniture which are restricted flat.

Water in Wood: Water in wood can be classified under two types:

- Bound water is chemically bound. It reaches the fibre saturation point (FSP), at approximately 30% moisture content (MC). This water intake depends on relative humidity (RH) and temperature.
- Free water – above FSP (>30% MC)

Bound water will not decrease until all free water has been removed. Dimensional change only takes place below FSP.[55]

Nicolaus states that bound water is classified as follows:

- Chemisorption (at 0 – 6% MC, by means of hydrogen bonding)
- Adsorbtion (6 – 15% MC)
- Capillary condensation (15% to FSP)

During chemisorption, the wood undergoes insignificant dimensional changes. During the adsorption phase, the cavity inside the cell wall fills up with water and presses the microstructure apart and wood starts expanding. During capillary condensation, the cavities are so full that capillary forces come into play leading to capillary condensation, this state ceases when FSP is reached.[56]

Wood cells: They are primarily elongated parallel to the tree stem. The macro- and microstructure, the anatomy and the chemical composition of wood are responsible for wood behaviour and its degree of resistance against decay.[57] See also *Chemical composition of wood* and *Microscopic structure of wood.*

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[55] Forest Products Laboratory, (1999) 3-5.
[56] Nicolaus, (1999) 23.
[57] Larsen, (2000) 26.

Wood sections: When wood needs to be identified, thin sections are taken, preferably from the three different directions, as shown in Figure 21

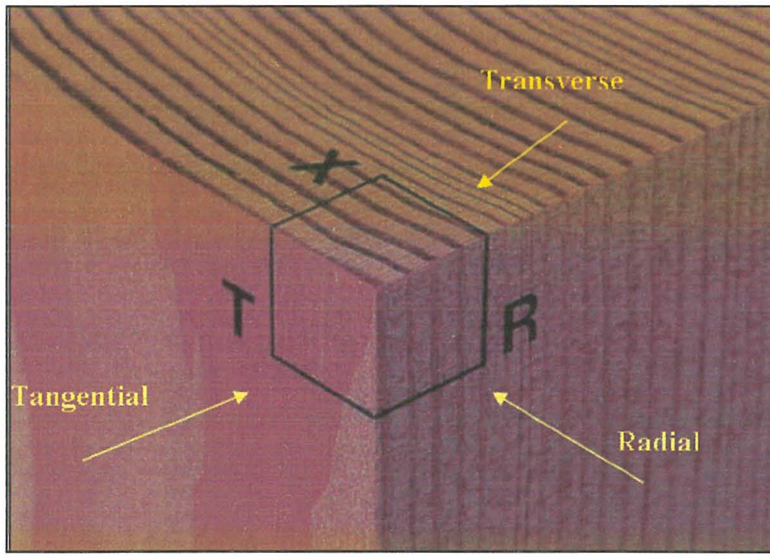

Figure 21 The three main directions of wood[58]

[58] Adapted from Hoadley, (1998) 6.

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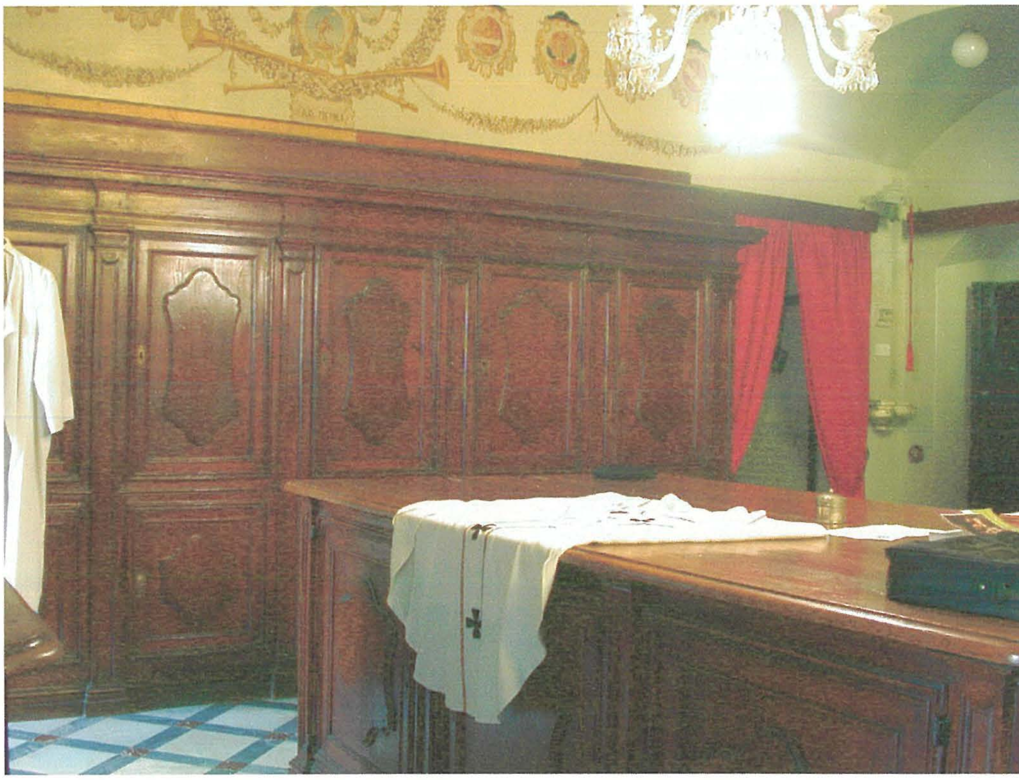

Plate 3 Sacristy of the Assumption of the Blessed Virgin Mary Church, Attard

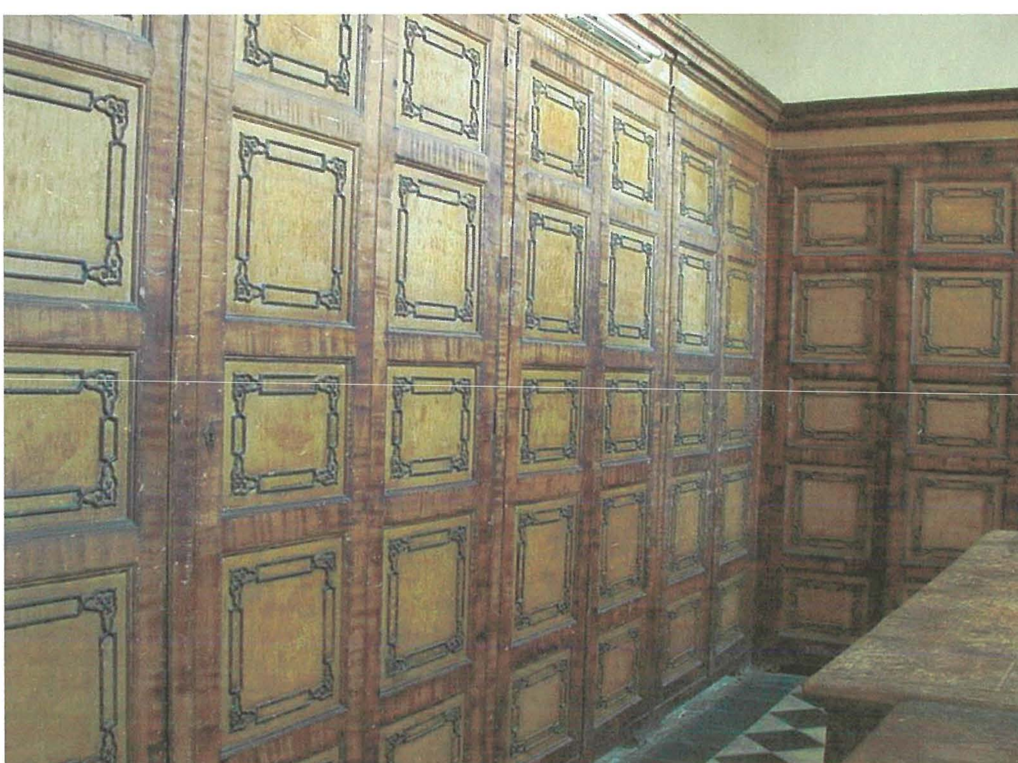

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Plate 5 New sacristy of the Annunciation Church, Balzan

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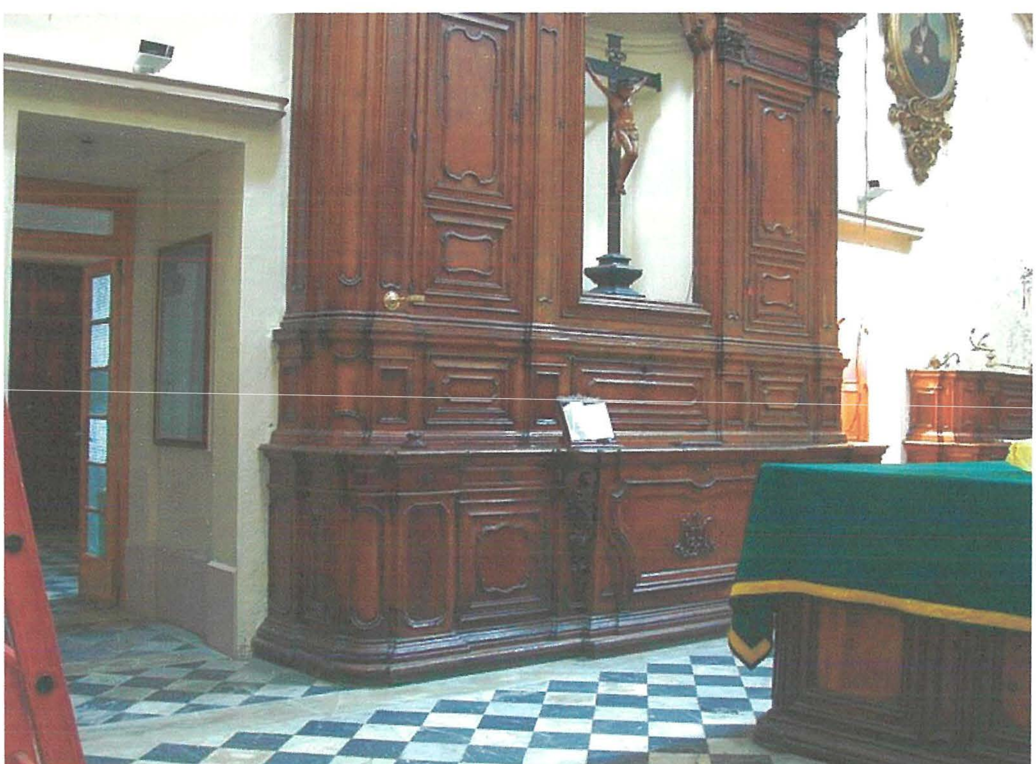
Plate 7 Old sacristy of St Helen's Basilica, Birkirkara



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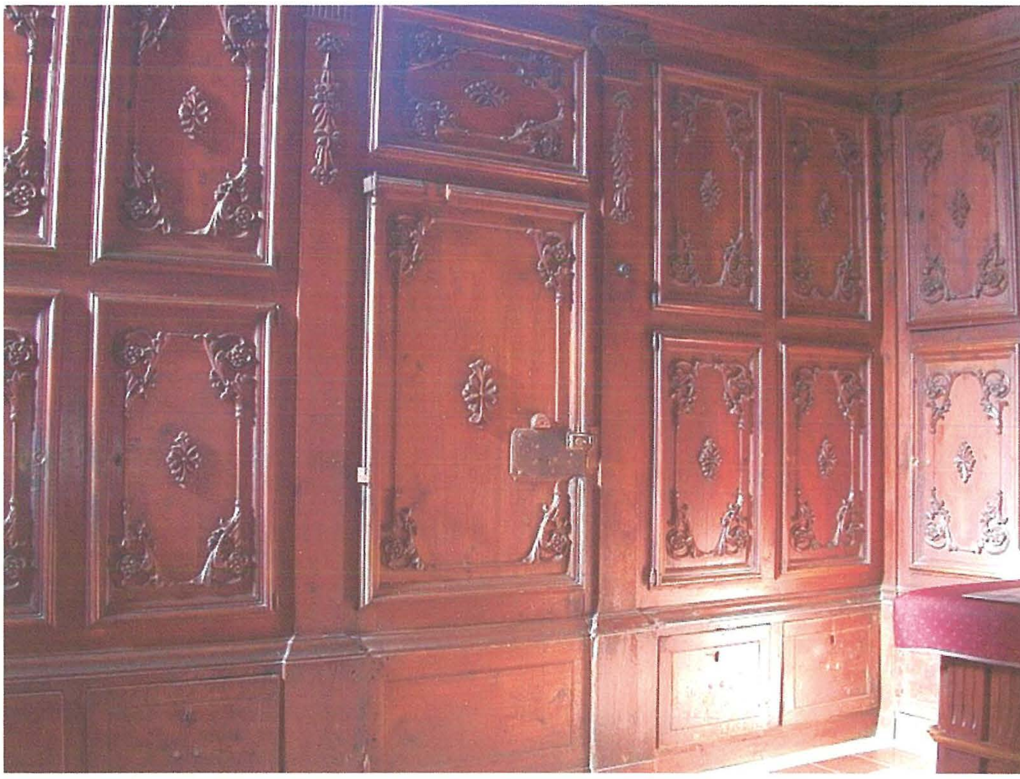

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Plate 22 Old sacristy of St Paul's Church, Rabat

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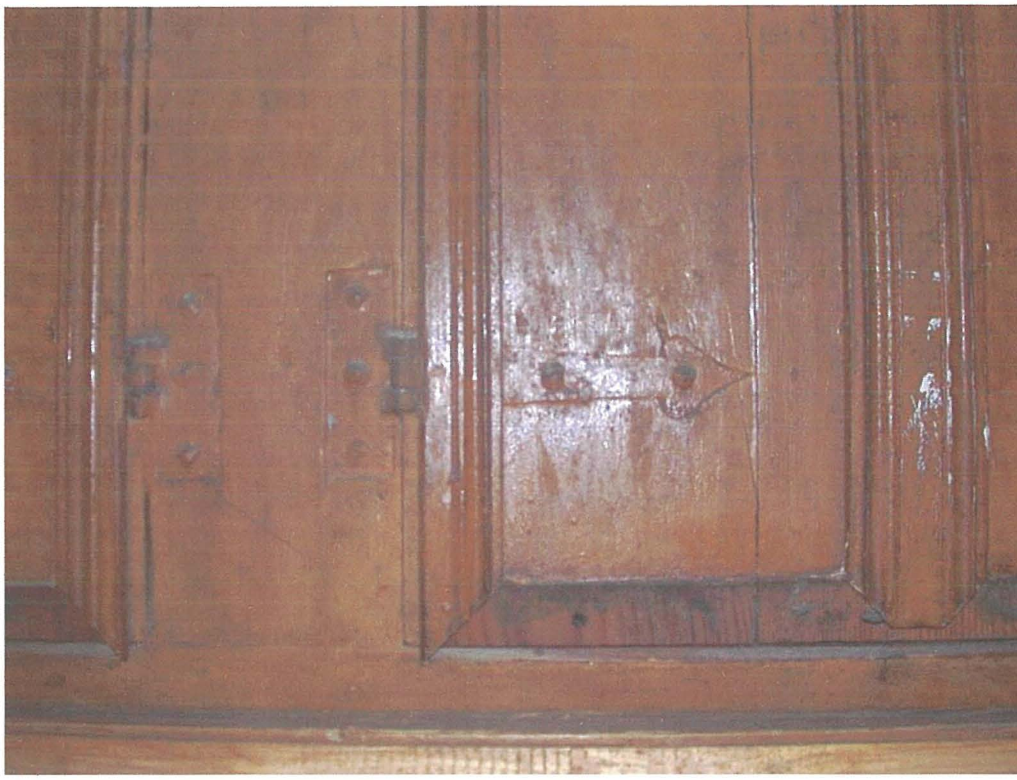
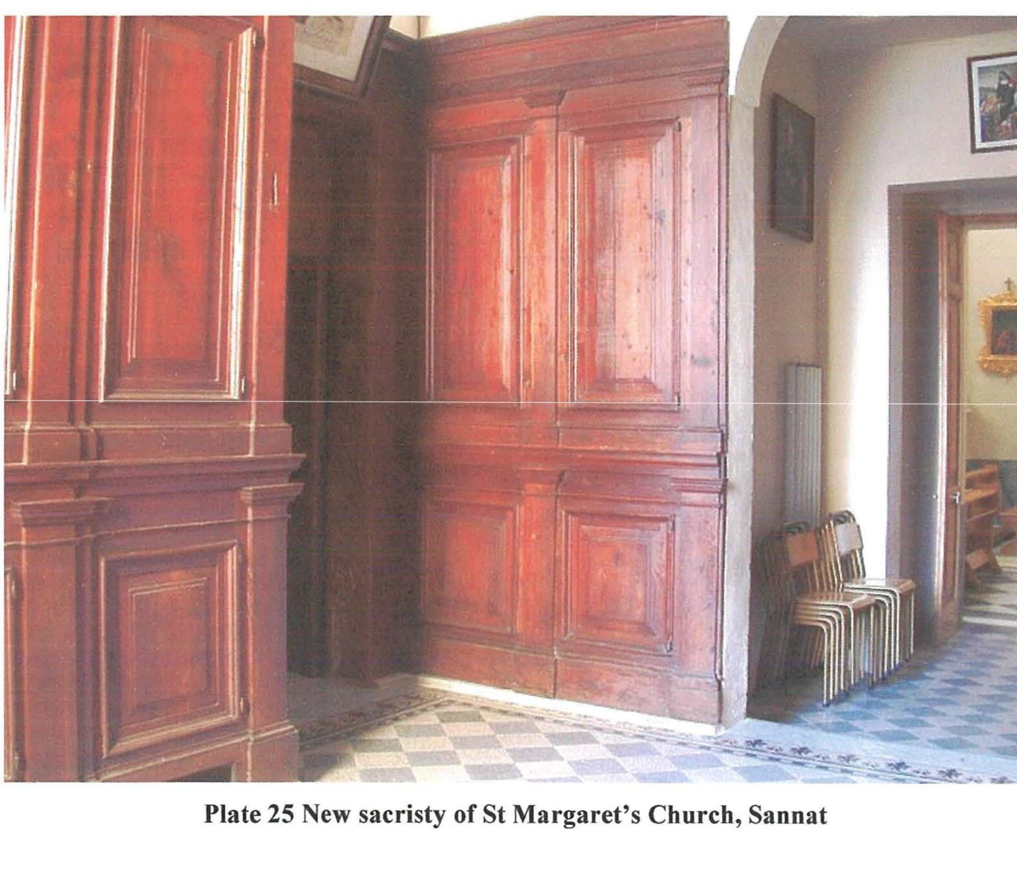


Plate 24 Old sacristy cupboard of St Margaret's Church, Sannat



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[1] Galea-Naudi (1997) 59

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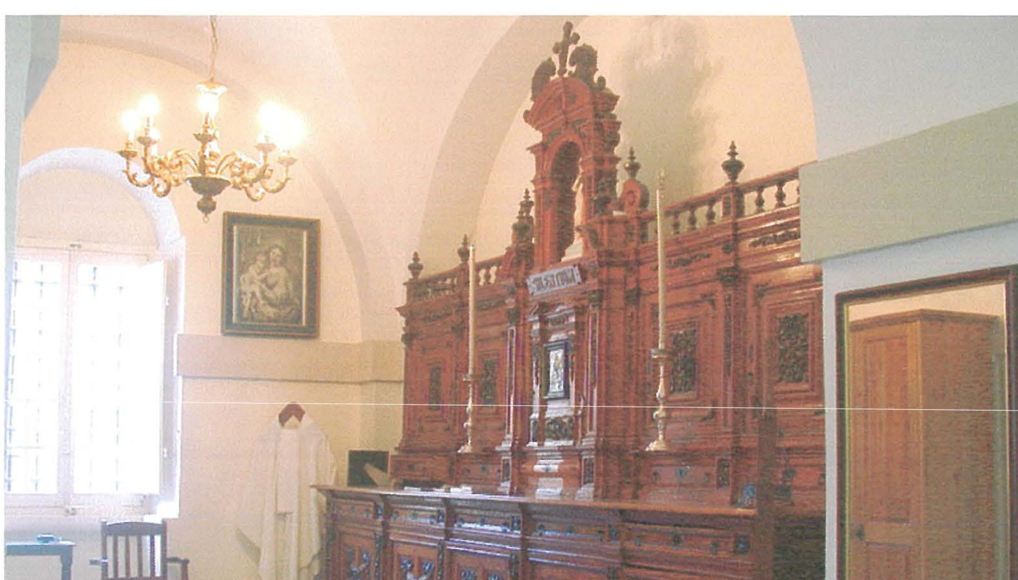

Plate 41 Sacristy of Our Lady of Divine Grace's Church, Victoria

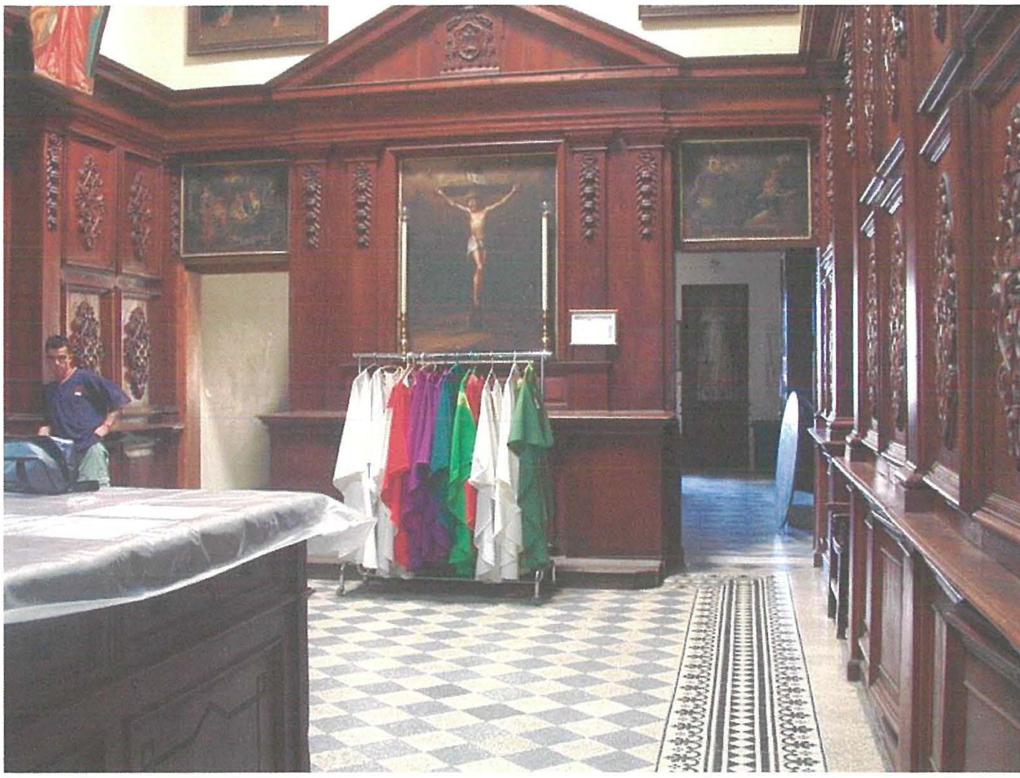

Plate 42 Sacristy of theNativity of the Virgin Mary's Church, Xagħra

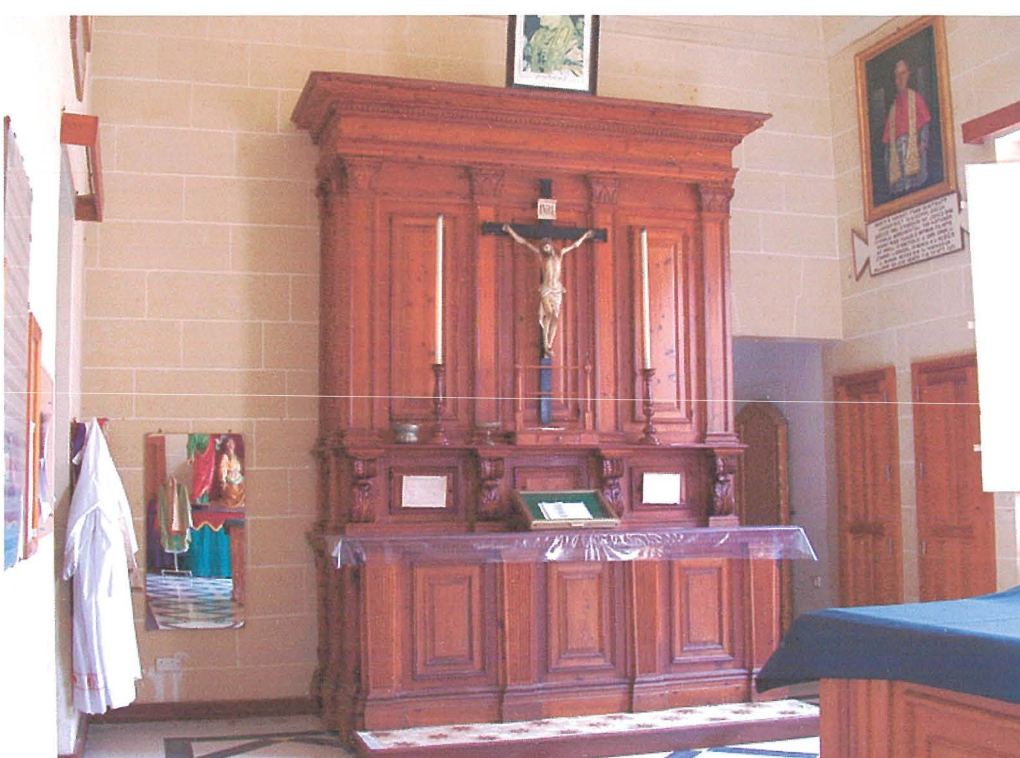

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Plate 44 New sacristy of St Philip's Church, Żebbuġ

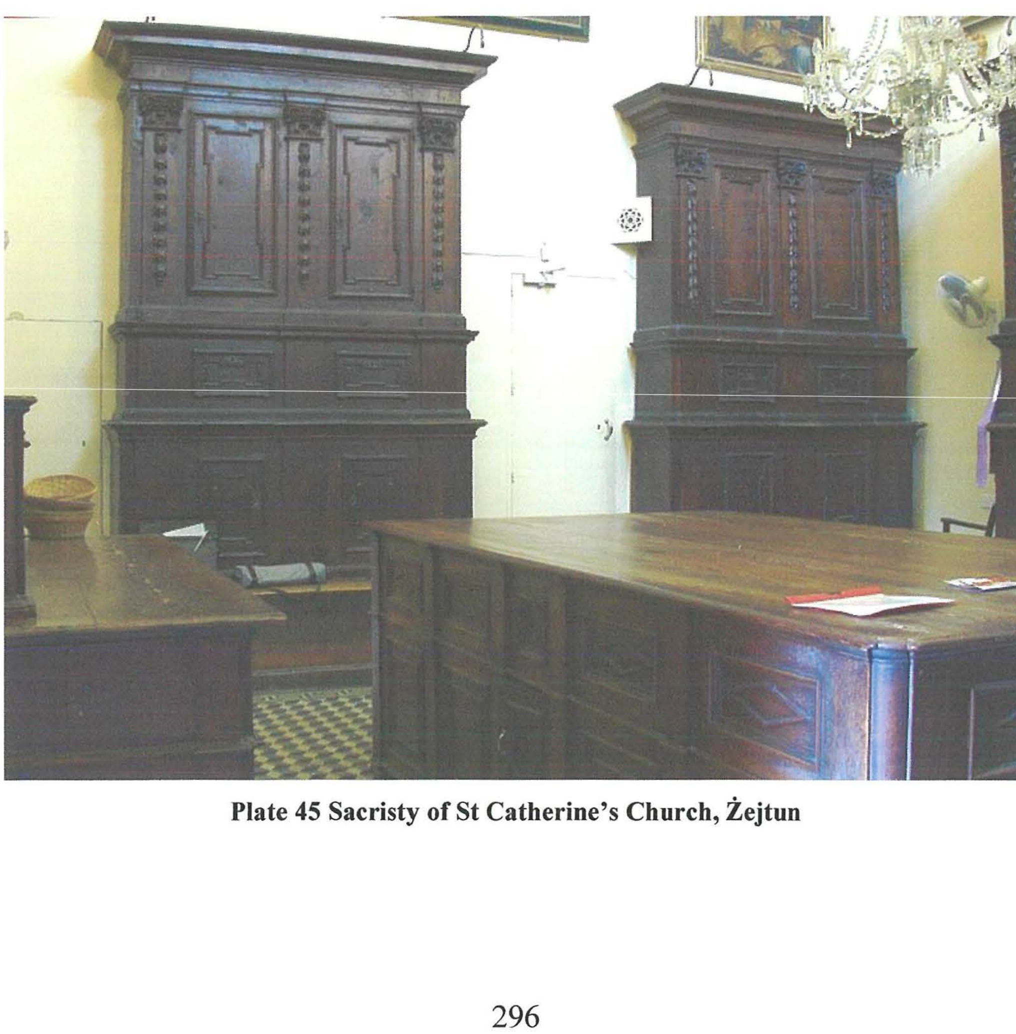

Plate 45 Sacristy of St Catherine's Church, Żejtun

Plate 46 Sacristy of St Catherine's Church, Żurrieq

Plate 47 Detail of a plugged hole in a side of an 18th century piece of furniture

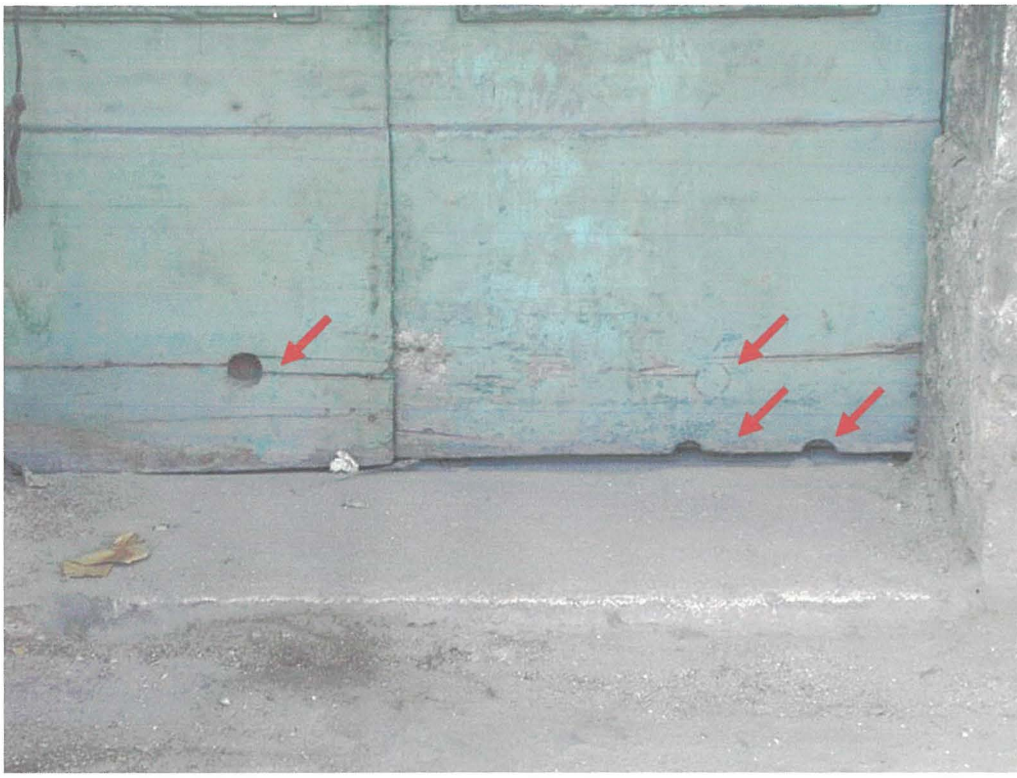

Plate 48 Lower external door panel with the extraordinary circular holes

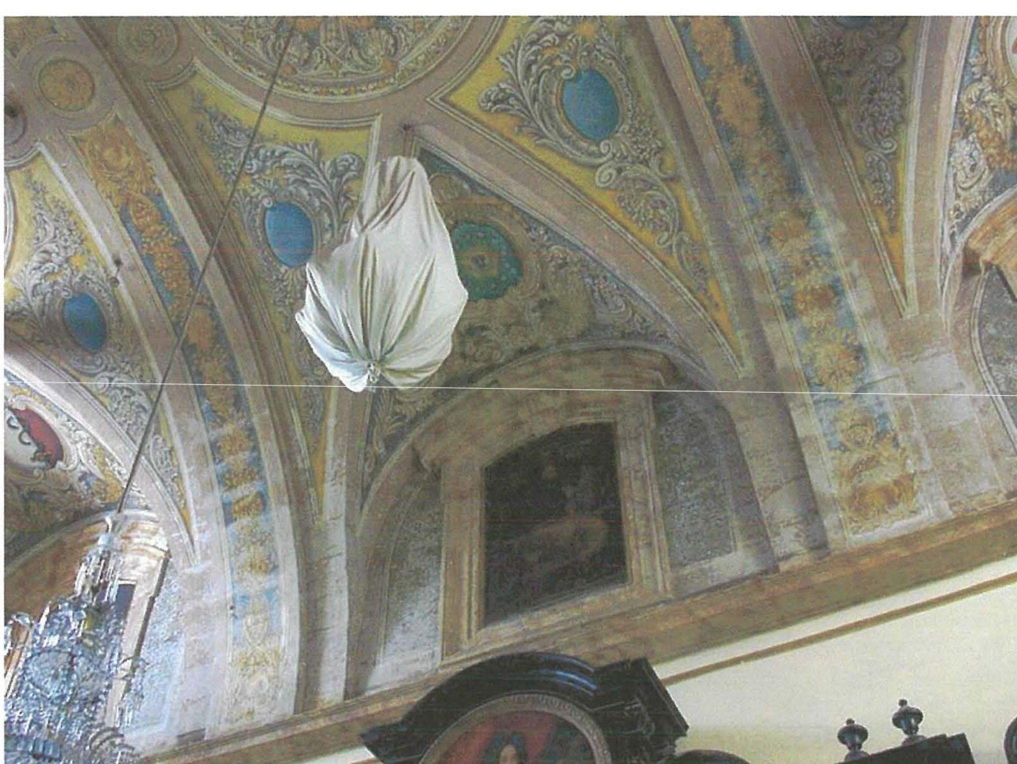

Plate 49 Decorative ceiling of St Paul's Sacristy, Valletta

Plate 50 One of the main sacristy furniture – St Paul's Church, Valletta

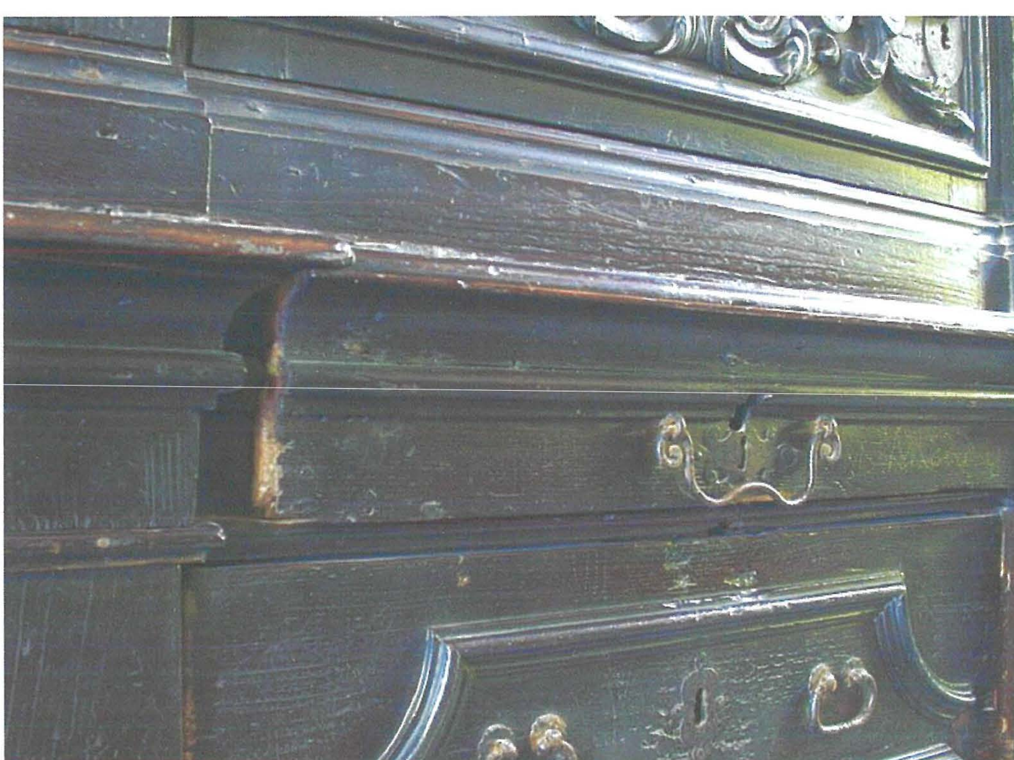

Plate 51 One of the shallow drawers located in furniture 'B' – St Paul's Church, Valletta

Plate 52 Dovetail joints used in drawer construction – St Paul's Church, Valletta

Plate 53 The cartouche present on sacristy furniture 'C' – St Publius Church, Rabat

Plate 54 Furniture 'A' – St Publius' Church, Rabat

Plate 55 Detail of graining technique – St Publius' Church, Rabat

Plate 56 Door reinforced with horizontal nailed members – St Publius' Church, Rabat

Plate 57 Detail of sacristy furniture 'C' – St Publius' Church, Rabat

Plate 58 Doorway decorated by marbling technique – St John's Conventual Church, Valletta

Plate 59 Sacristy cupboards – St John's Conventual Church, Valletta

Plate 60 Hangers fixed to the south wall furniture – St John's Conventual Church, Valletta

Plate 61 Furniture and wall decorations – St Philip's Church, Żebbuġ

Plate 62 South wall furniture – St Philip's Church, Żebbuġ

Plate 63 One of the doors on the west wall furniture – St Philip's Church, Żebbuġ

Plate 64 Central cupboard – St Philip's Church, Żebbuġ

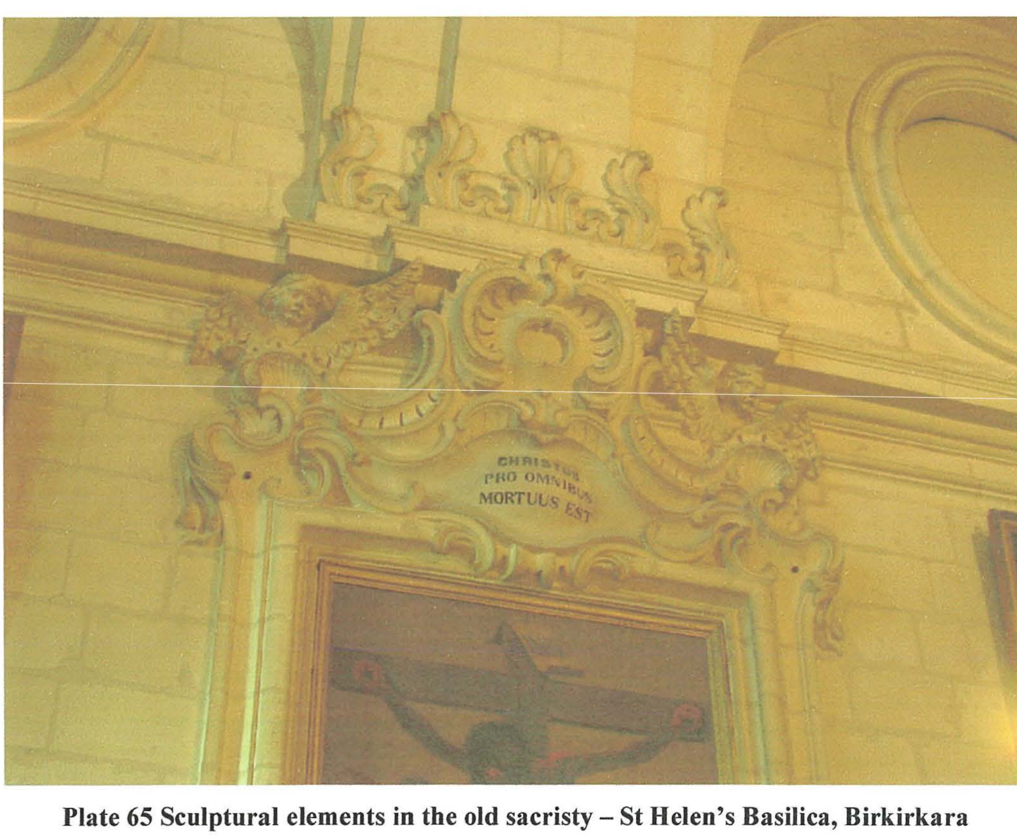

Plate 65 Sculptural elements in the old sacristy – St Helen's Basilica, Birkirkara

Plate 66 Furniture piece 'B' in the old sacristy – St Helen's Basilica, Birkirkara

Plate 67 Furniture piece 'C' in the old sacristy – St Helen's Basilica, Birkirkara

Plate 68 Furniture piece 'D' in the old sacristy – St Helen's Basilica, Birkirkara

Plate 69 Central cupboard in the old sacristy – St Helen's Basilica, Birkirkara

Plate 70 Main and central pieces of furniture – St Dominic's Church, Valletta

Plate 71 Furniture part 'C' – St Dominic's Church, Valletta

Plate 72 Detail of cupboard 'A' – St Dominic's Church, Valletta

Plate 73 Padlock used to lock two doors, previous intervention – St Dominic's Church, Valletta

Plate 74 Furniture piece 'A' in the new sacristy – St Helen's Basilica, Birkirkara

Plate 75 Furniture piece 'B' in the new sacristy – St Helen's Basilica, Birkirkara

Plate 76 Furniture part 'C' in the new sacristy – St Helen's Basilica, Birkirkara

Plate 77 Detail of door finish, furniture 'B' in the new sacristy – St Helen's Basilica, Birkirkara

Plate 78 Decorative ceiling of the sacristy – Stella Maris Church, Sliema

Plate 79 Central cupboard – Stella Maris Church, Sliema

Plate 80 South wall furniture – Stella Maris Church, Sliema

Plate 81 Detail of metal drawer runner – Stella Maris Church, Sliema

Plate 82 Pieces of plywood attached to support door – Stella Maris Church, Sliema

Plate 83 Furniture piece 'B' – Transfiguration Church, Lija

Plate 84 Furniture piece 'D' – Transfiguration Church, Lija

Plate 85 Central cupboard – Transfiguration Church, Lija

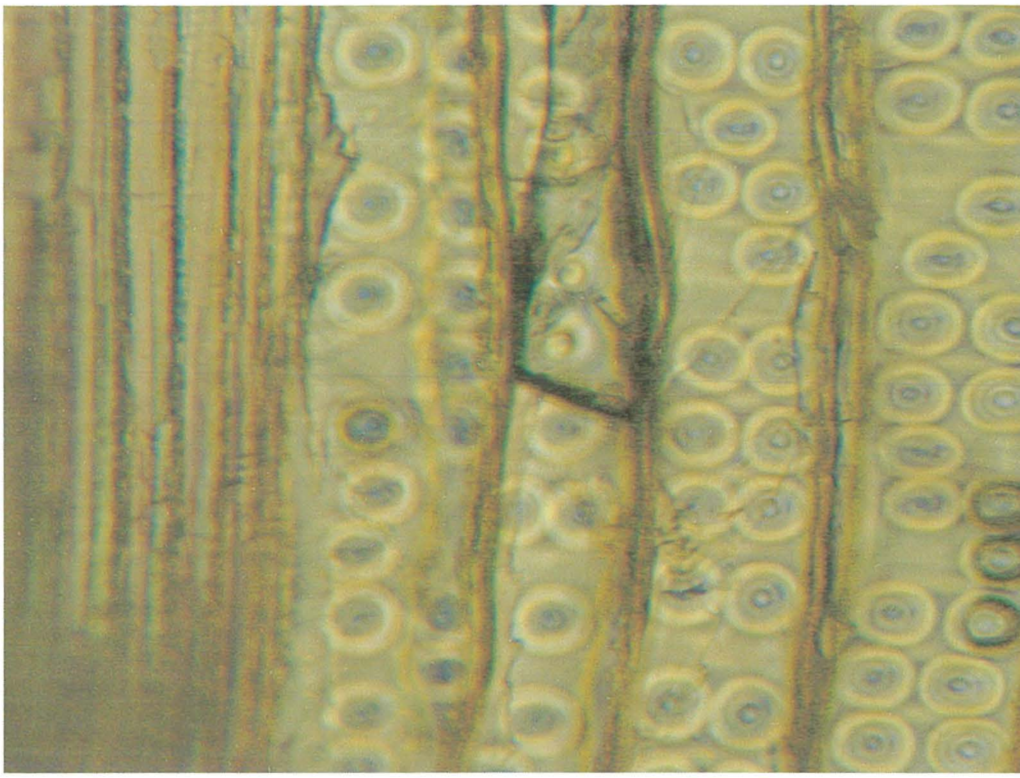

Plate 86 Radial microscopic section of *Larix decidua* from a door - Visitation Church, Gharb

Plate 87 External wall of St Helen's Basilica old sacristy, Birkirkara

Plate 88 External wall of St John's New Sacristy, Valletta (A)

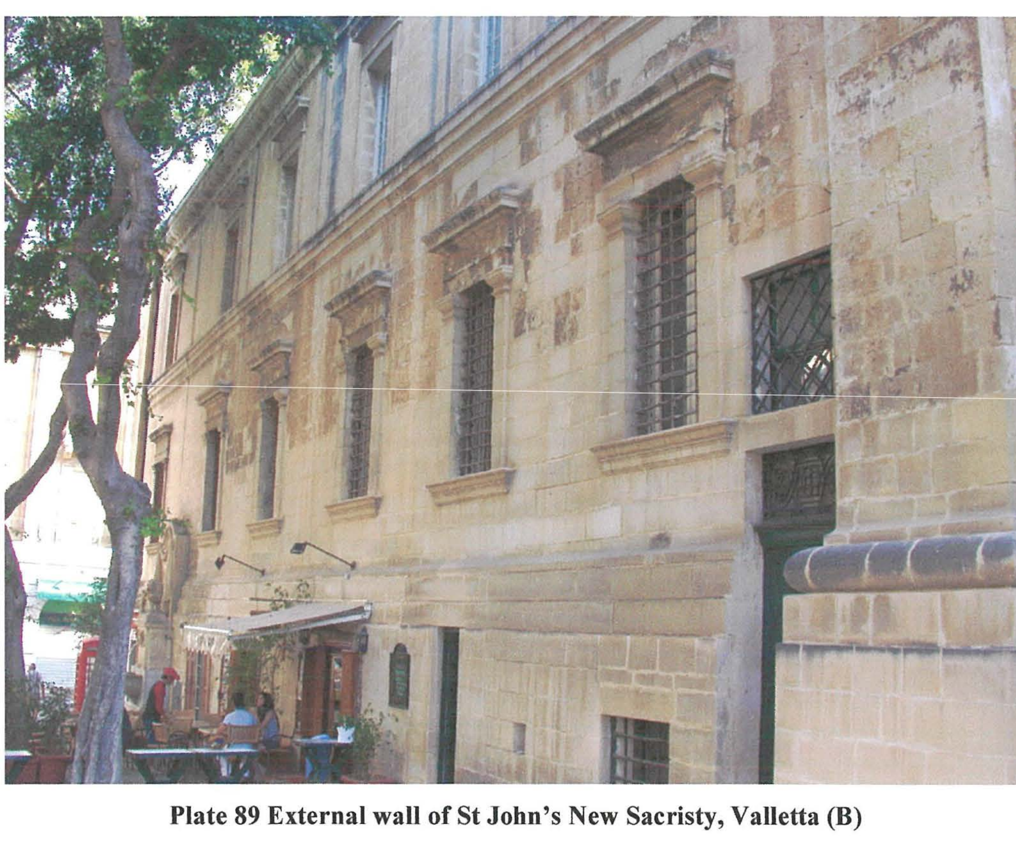

Plate 89 External wall of St John's New Sacristy, Valletta (B)

Plate 90 View of the bench lid used for the computer predictions, old sacristy – St Helen's Basilica, Birkirkara

Plate 91 View of lower door used for the computer predictions, new sacristy – St John's Conventual Church, Valletta

Plate 92 Abrasions and scratches on a door surface, new sacristy – St Helen's Basilica, Birkirkara

Plate 93 Chairs and benches close to furniture increasing the risk of damage, new sacristy – St Helen's Basilica, Birkirkara

Plate 94 New sacristy cupboard lock that replaced the original one

Plate 95 Sacristy furniture cabinet in a state of neglect

Plate 96 Sacristy furniture sagging due to excessive weight –St Paul's Church, Valletta