Norwegian Building Research Institute

Stig Geving, Tore Henrik Erichsen,
Kristine Nore and Berit Time

Hygrothermal conditions in wooden claddings

Test house measurements

Report from the R&D-programme «Climate 2000»

407 Project report 2006

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Preface

This report presents overall results from a field investigation of wooden cladding carried out in order to improve our knowledge on the close relationship between microclimatic conditions and cladding performance. The work has been carried out as part of project 9 *Requirements for façade systems in relation to driving rain* loads within the Norwegian research and development programme *Climate 2000 - Building constructions in a more severe climate*.

The *Climate 2000* programme's principal objectives are to develop solutions in principal for building structures resulting in both increased durability and reliability in the face of external climatic impact, and to survey the possible impacts of climate change on the built environment. The intention is to define more accurate criteria and Codes of Practice for the design and construction of critical elements of building envelopes. *Climate 2000* is an important part of the continuous development of the Building Research Design Sheets in the SINTEF Building Research Series, and product documentation in the form of technical approval and certification.

The programme is being managed by SINTEF Building and Infrastructure and carried out in co-operation with the Norwegian Defence Estates Agency, the Research Council of Norway (NFR), the Norwegian State Housing Bank, Norway's Directorate of Public Construction and Property (Statsbygg), the Norwegian Financial Services Association (FNH), National Office of Building Technology and Administration (BE), the Norwegian University of Science and Technology (NTNU) and a large number of key players in the construction industry. The programme was initiated in August 2000, and will continue until the end of 2007.

The authors gratefully acknowledge the assistance from the following partners; Brødr. Sunde as, Department of Civil and Transport Engineering at NTNU, Icopal as, Isola as, Isolasjonsprodusentenes forening (IPF), Jotun A/S, maxit as, Moelven ByggModul AS, Norwegian Association of Ventilation- and Tinsmith Companies (VBL), Norwegian Directorate for Cultural Heritage, Protan A/S, Rambøll Norge AS, A/S Rockwool, and finally the EU Northern Periphery Programme, project *External Timber Cladding in Maritime Conditions*.

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Trondheim, October 2006

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Summary

In Trondheim, different variations of wood cladding design have been used on a test house, as part of the Norwegian research programme “Climate 2000”, and the Northern Pheriphery Programme INTERREG III B 2000-2006 Project – External Timber Claddings in Maritime Conditions. The aim of this investigation have been to increase our understanding of the relation between microclimatic conditions and the responding performance of wooden claddings, according to orientation, design of ventilation gap and wood qualities.

On each of the east and west façades of the test house 14 full height test sections were arranged. Each of these test sections had a specific variant of cladding. The following parameters were varied:

- Driving rain exposure (orientation)
- Ventilation gap opening at top and bottom of cladding
- Surface treatment of the cladding
- Growth rate of wood

The driving rain exposure varies considerably between the western and eastern oriented facades. While the western facades are exposed to a high amount of driving rain, only small amounts of driving rain reaches the eastern oriented facades.

The test claddings were horizontally fixed boards of Norway spruce (*Picea abies L. Karst*). The timber claddings (rain screens) were assembled by a series of boards fixed to vertical support battens (with thickness 23 mm) which were designed to allow uninterrupted drainage and ventilation of the cavity behind the cladding. The ventilation gap opening at top and bottom of the cladding were either 0 mm (no ventilation), 4 mm or 23 mm (full opening).

The average dry density of the instrumented cladding boards were 385 kg/m^3 for the fast grown spruce and 460 kg/m^3 for the slow grown spruce. Two types of surface treatments were investigated; a water dispersed acrylic/alkyd painting and an oil dilutable alkyd painting.

The measurements in the wall constructions started in January 2004 and lasted till December 2005. The logging system stored hourly values. The cladding boards were instrumented with temperature sensors and moisture content sensors (in wood) at two different heights, respectively 1,0 m and 3,0 m from the bottom of the cladding.

The results showed clearly that:

- Air gap openings in the top and bottom part of the cladding limits the moisture content in wooden claddings exposed to driving rain.
- An air gap opening in the top and bottom part of the cladding equivalent to a 4 mm continous air gap is sufficient to limit the moisture content of wooden claddings exposed to driving rain.
- For climates, orientations or geometries where only small amounts of driving rain hits the wall the wooden cladding might even perform better with no planned air gap openings at all.
- The results showed relative little difference between oil based and water based paint in regard to the risk for decay and microbiological growth.
- Regarding untreated claddings we found that the risk for decay and microbiological growth was generally higher for these cladding types compared to painted claddings. It may however be said that even if the risk is higher with untreated claddings, the results do not indicate that the risk is critically higher.

- The results showed little difference between slow grown and fast grown spruce in regard to the risk for decay and microbiological growth.

The practical recommendation for wooden claddings based on previous experience and the results of this study are then as follows:

- Wooden claddings should be ventilated in the top and bottom part, regardless of degree of exposure to driving rain.
- Openings in top and bottom part of the wall equivalent to a 4 mm continous air gap is sufficient. The openings do however not need to be continous, see for instance a traditional Norwegian vertical board and board cladding where there are openings only behind the top board.
- There must be a drainage system consisting of :
    - An air cavity behind the panel wide enough and with a system of e.g. support battens/counter battens that ensure that water penetrating the panels do not reach the wind barrier in amounts that may damage the inner part of the wall.
    - Drainage opening(s) in the bottom part of the wall minimum 5 mm wide.

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- APP. 2: TEST HOUSE CONFIGURATIONS
- APP. 3: METHOD FOR CALCULATING MOULD GROWTH POTENTIAL
- APP. 4: GRAPHICAL RESULTS

1 Introduction

1.1 Purpose of study

Wooden facade claddings are commonly used in Scandinavia. In coastal areas of Norway the cladding traditionally has horizontal boards, whereas in the inland regions mostly vertically oriented cladding boards are seen. While vertical panelling directly onto the log walls was a durable design in a dry inland climate, this was not the case in coastal areas exposed to severe wind driven rain. Here vertical battens were first mounted on the log wall and then the cladding boards were mounted horizontally, i.e. a ventilated cladding, see Nore (2004).

As the demand for thermal insulation has increased, the hygrothermal condition for the cladding has changed. In well insulated wall assemblies, the cladding temperature is lower and temperature gradients are smaller, compared to traditional walls. Thus the drying out potential is smaller, and the risk of decay may be higher.

On modern buildings it is experienced that unventilated claddings may perform well in dry, inland situations. In Norway it is, however, generally recommended to design wooden claddings as ventilated claddings, i.e. with a ventilated air gap behind the cladding. This is considered a safer solution regarding possible decay than unventilated claddings. In spite of this, rotting and accelerated decay have in some cases been reported even on ventilated claddings after only a few years, see Christensen (1999). As a consequence of these cases and also as an effort to improve design recommendations adapted to the climate on the building site, one is asking the question: How do parameters such as wood quality, surface treatment, ventilation gap width and design of ventilation gap openings influence the hygrothermal condition and general performance of the wood cladding?

In Trondheim, different variations of wood cladding design have been used on a test house, as part of the Norwegian research programme “Climate 2000”, see Lisø et al. (2005), and the Northern Pheriphery Programme INTERREG III B 2000-2006 Project – External Timber Claddings in Maritime Conditions. The aim of this investigation is to increase our understanding of the relation between microclimatic conditions and the responding performance of wooden claddings, according to orientation, design of ventilation gap and wood qualities.

Parts of the test setup and measurement data have previously been presented in various scientific articles. A short description of these articles are given in Chapter 5.14.

1.2 Background

Nore (2004) gives a literature review of wooden cladding design. Kvande et al. (2003) discusses ventilated claddings in general and sums up Norwegian experience from several building defect cases, as well as present design recommendations. It is concluded that defects normally are due to lack of sufficient ventilation and/or drainage of the cladding, or inappropriate detailing of for instance flashings. A subdivision of Norwegian climate into three different climatic zones according to wind driven rain conditions is suggested. However, criteria for distinguishing these zones are not yet fully developed.

The air gap behind the cladding serves multiple purposes. A correctly designed air gap should fulfil the following performance requirements as given in Kvande et al. (2003):

- Separate the exterior rain screen from the wind barrier in order to prevent inwards water transport by capillary suction or gravity
- Draining out water that may have penetrated through the rain screen

- Allow drying of excess moisture in the internal parts of the wall assembly
- Allow drying of the cladding on the reverse side
- Equalize the pressure on the cladding to avoid driving rain being pressed into the wall.

Andersen (2000) gives a review of the physics of a ventilated air gap and describes a calculation model for estimation of airflow velocities in ventilated cavities under different conditions.

Hansen et al. (2002) investigated both experimental and by simulation, the effect of a ventilated or unventilated cavity behind the cladding on moisture conditions in timber frame walls. They concluded that walls with an unventilated cavity were not inferior, in terms of the moisture content behind the wind barrier, to the walls with a ventilated cavity. They emphasised, however, that cavities always should be drained and that venting in order to equalise pressure differences might prove necessary at exposed sites.

Gudum (2003) designed and validated a model for analysing the effect of ventilation and insulation thickness upon the moisture load of the wall. She argues that a wooden cladding would not deteriorate if an air gap is missing, but the construction is more robust and less sensitive to the quality of the workmanship with the air gap included. She recommends further investigation of the influence of the air gap, especially according to climatic influence and orientation of the wall.

After the so called “cladding disaster”, when many Norwegian houses with common cladding design experienced rot attacking the claddings after less than ten years of service, extensive investigations were done, especially on the influence of the paint and the air gap. These investigations are summed up in Christensen (1999), but give no significant conclusions.

2 Description of the test house

2.1 Test house

The test house is located on a field station belonging to the SINTEF Building and Infrastructure and the Norwegian University of Science and Technology (NTNU). The field station is located on an open field at Voll (Jonsvannsveien 159) in Trondheim, approximately 6 km south-east of the centre of the city. The exact location is N63°25' E10°28'. The field station consists of a test house with removable roof and wall elements (building A), another test house which can be rotated for wind pressure studies (building C), an automatic weather station (also described in this report) and a small measurement house (building B) in connection with the weather station, see Figure 2.1 and 2.2. The test house is shown in Figure 2.3.

The roof and facades of the test house consist of prefabricated sections fixed to the outside of a steel frame structure, see Figure 2.4. The test house is orientated in north-south direction and has the following indoor dimensions: length 10.7 m, width 3.45 m and height 3.5 m. The roof sections span from facade to facade, and have a 1:40 slope.

All sections are 1,2 m wide and they are separated from each other regarding air and moisture transfer, by use of polyethylene foil. The sections may be changed individually without disturbing the neighbour sections. There are a total of 16 wall sections on the western and eastern facades and 8 roof sections, see Figure 2.5. The elements are given names according to orientation of the wall (codes = W1-W8 and E1-E8, where W = west oriented wall, E=east oriented wall). For the cladding tests each wall element has two different cladding configurations, each with a width of 0,6 m. Each cladding configuration is given names according to the element, and whether it is on the southern or northern part of the element (code = S or N), i.e. W2-S is the cladding configuration on the southern part of element W2.

The test house is equipped with a low temperature electric floor heating system, balanced mechanical ventilation with heat recovery and an automatic air humidifying system. In this project the ventilation and humidifying system is not used. Description of the logging system and climatic control system is given in appendix 2.

Figure 2.1
An overview of the test station from south-west

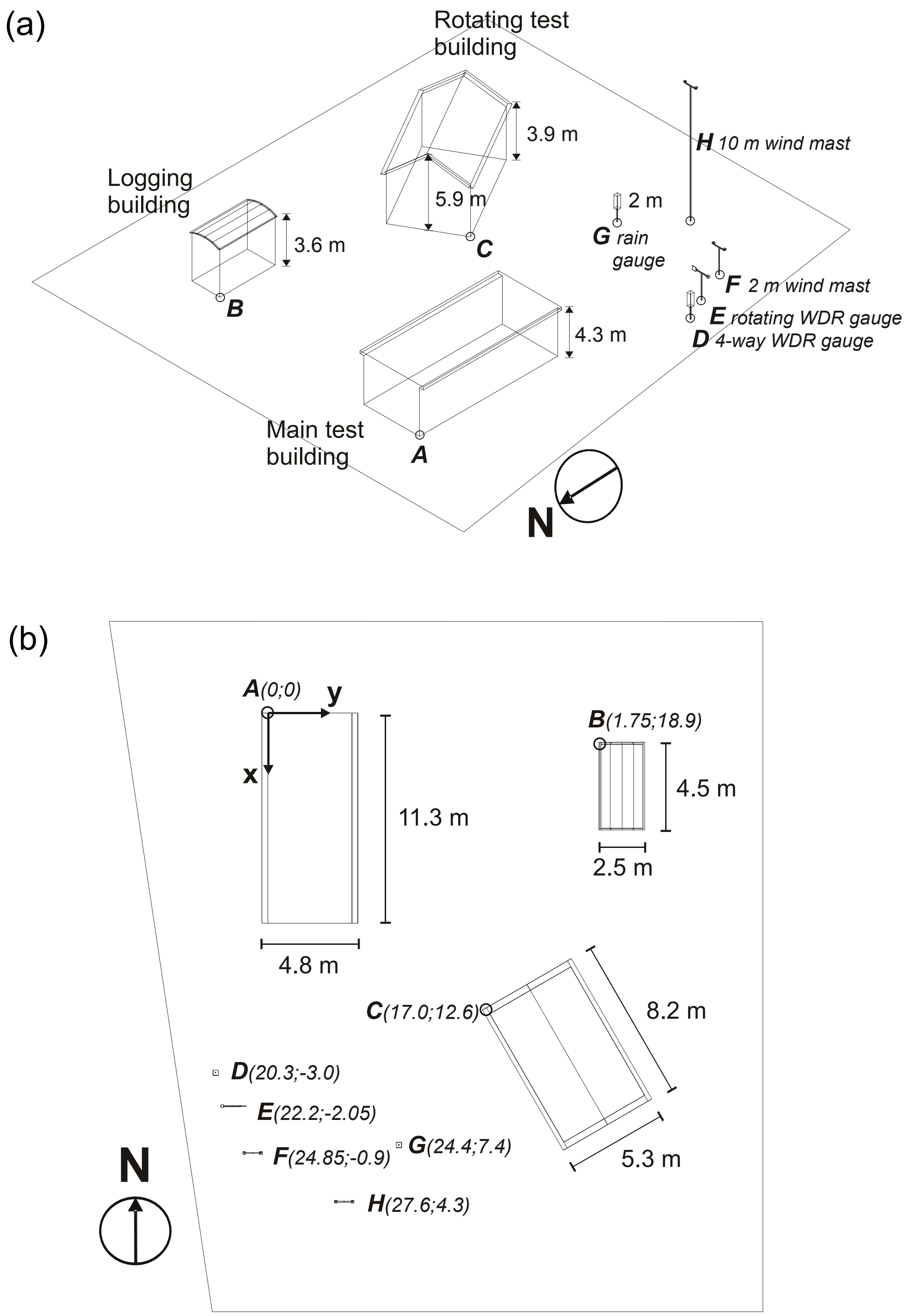

Figure 2.2
Field station of SINTEF Byggforsk and NTNU. It should be notetd that only building A is part of this study. : (a) Perspective view and (b) top view with indication of the building dimensions and the location (x, y co-ordinates) of the buildings and measurement equipment relative to point A (north-west corner of the flat-roof test building) (in m). (Nore et.al., 2006)

Figure 2.3
The eastern side of the test house.

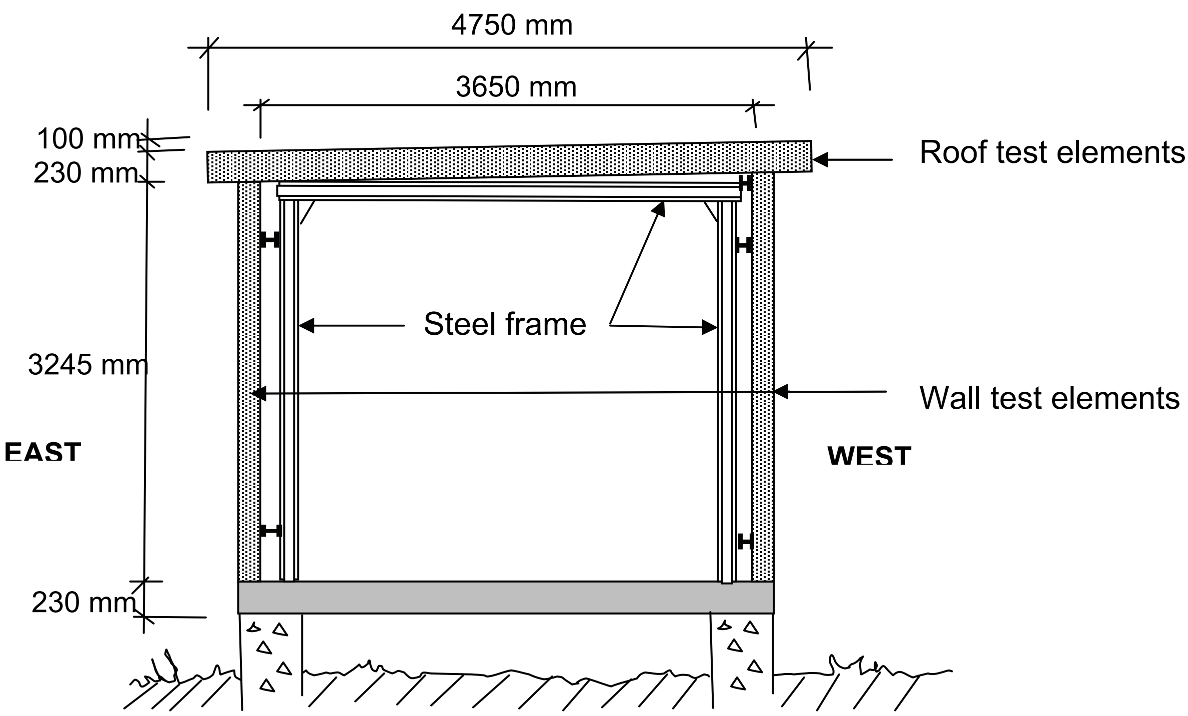

Figure 2.4
East-west section of the test house showing how the elements are fixed to the steel frame structure.

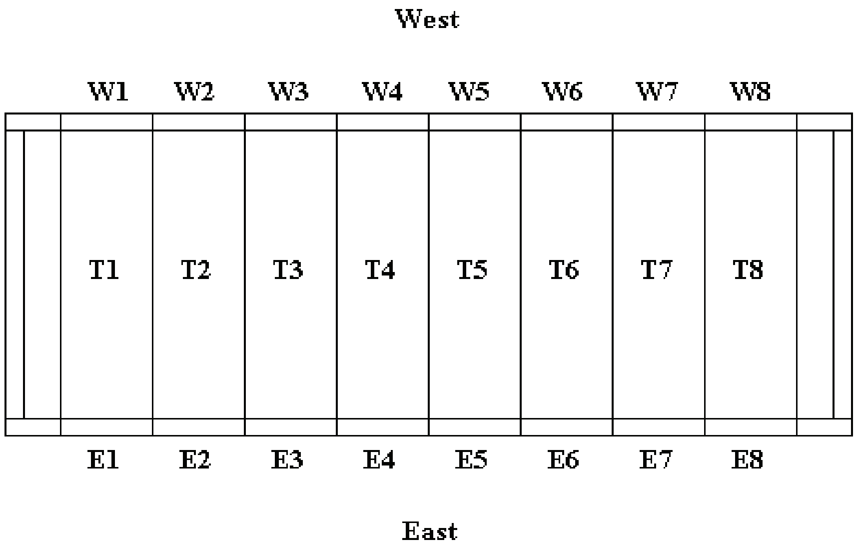

Figure 2.5
Plan of the test house in Trondheim, showing the location of the wall and roof test elements.

2.2 Automatic weather station

Outdoor climatic data are measured by a Milos 500 Vaisala automatic weather station (AWS) located 17 m to the south of the test house, see Figure 2.6. The AWS is operated by the Norwegian Meteorological Institute in cooperation with the Norwegian Building Research Institute, ensuring a good quality of the measurements.

To extend the measurements of the climate in regard to this project, complementary free wind-driven rain load is measured at the same location. This includes both a rotating driving rain gauge and driving rain gauges in the four cardinal directions, see Figure 2.7

Wind-driven rain gauges are also mounted on the walls of the test house (see Figure 2.8), both in order to investigate the distribution of wind-driven rain on a low-rise building and to find the relation between wind-driven rain, time of wetness (the period when the surface is covered with a water film) and the moisture gradient response of the wooden cladding. The wind-driven rain is measured at 11 different places on the test house. The orientation that gives the highest total amount of driving rain on a facade in Trondheim is towards west, see Figure 4.6.. 8 driving rain gauges are located at the west-facing façade in order to measure the driving rain distribution on the façade with the highest driving rain strain. The north and south façade have one driving rain gauge each, i.e. on the east corner of the northfacing wall and the west corner of the southfacing wall. The east-facing wall has one driving rain gauge in the middle of the façade. Thus both the meso- and the microclimate at the field station are recorded. All meteorological data are as standard recorded at one hour intervals, with the possibility to choose other time intervals for special purposes. See Nore et.al. (2006) for more details regarding the wind-driven rain measurements.

A detailed description of the AWS and the climatic measurements are given in Appendix 1.

Figure 2.6
The automatic weather station.

a. Directional driving rain gauge

b. Rotating driving rain gauge

Figure 2.7
Free field driving rain gauges

Figure 2.8
Wall mounted driving rain gauge

2.3 Indoor climate

The indoor air temperature was controlled at a constant level of approximately 20 ^{o}C. During summer the temperature might get higher in periods. The test house was not ventilated or humidified, so the RH was allowed to fluctuate depending on mainly the outdoor temperature and RH. Both the indoor air temperature and RH was logged every hour.

3 Description of test claddings

3.1 Wall element

The overall dimensions of the wall sections are 1190 mm x 3250 mm, with stud and top/bottom plate dimensions of 48 mm x 148 mm (spruce). A more detailed description can be found in Geving and Uvsløkk (2000). A PE-foil isolated the test wall perimeter from the surrounding constructions in terms of mass transfer, and adiabatic conditions were maintained at the wall perimeter with respect to heat transfer. From the interior side the construction is built as follows:

- 12 mm wood fibre board or gypsum board
- 0,15/0,2 mm polyethylene foil
- 150 mm glass fibre insulation (density ≈ 18 kg/m^3, thermal conductivity = 0,036 W/mK).
- 9 mm gypsum board, exterior grade
- 23 mm air cavity (ventilated or unventilated)
- 19 mm shiplap wooden cladding

For two elements (W5N and E5S) the vertical battens were removed and the cladding mounted directed onto the windbarrier in May 2005 (i.e. from 23 mm to 0 mm air cavity)

The equivalent air layer thicknesses for these materials are given in Table 3.1.

Table 3.1
Measured equivalent air layer thickness

Material	s_d (m)
Wood fibre board (12 mm)	0,52
Polyethylene foil (0,15 mm)	63
Gypsum board (9 mm)	0,08

3.2 The test claddings

On each of the east and west façades of the test house 14 full height test sections are arranged. Each of these test sections has a specific variant of cladding. The following parameters are varied:

- Driving rain exposure (orientation)
- Ventilation gap opening at top and bottom of cladding
- Surface treatment of the cladding
- Growth rate of wood

The driving rain exposure varies considerably between the western and eastern oriented facades. While the western facades are exposed to a high amount of driving rain, only small amounts of driving rain reaches the eastern oriented facades.

The test claddings are horizontally fixed boards of Norway spruce (*Picea abies L. Karst*). The timber claddings (rain screens) are assembled by a series of boards fixed to support battens which are designed to allow uninterrupted drainage and ventilation of the gap behind the cladding. The ventilation gap opening at top and bottom of the cladding are either 0 mm (no ventilation), 4 mm or 23 mm (full opening), see Figure 3.1.

Each cladding board is carefully marked with its origin tree. The growth places of the trees are known (producer: Aavatsmark Sagbruk). For each of the 60 boards selected for instrumentation; weight, length and moisture content were measured. The average dry density of the instrumented cladding boards are 385 kg/m^3 for the fast grown spruce and 460 kg/m^3 for the slow grown spruce.

Two types of surface treatments are investigated; a water dispersed acrylic/alkyd painting (Production name = “Jotun Demidekk Optimal”) and an oil dilutable alkyd painting (production name = “Drygolin Extrem Oljedekkbeis”). Before applying the paint the claddings were treated with a primer (Jotun Visir). Two layers of paint were used.

The equivalent air layer thicknesses for the two types of surface treatments have been measured by the wet-cup method. Specimens were taken from the panels and the combined vapour resistance of paint and wood were measured. Subtracting the resistance of the wood the oil dilutable painting has S_d = 2,5 m and the water dispersed acrylic/alkyd painting has S_d = 1,3 m. There are however some uncertainties of these measurements due to a limited number of specimens.

Three test sections are left untreated.

The various combinations of parameters for the different test sections are shown in Table 3.2.

Table 3.2
Combinations of parameters for the various test sections

Test sections [1)]	Growth rate [2)]	Air gap opening at top and bottom of cladding (mm)	Type of surface treatment [3)]
W1-S & E1-S & E2-S	H	0	A
W1-N & E1-N	S	0	A
W2-S & E2-N	S	4	A
W2-N & E3-N	S	23	A
W3-S & E3-S	H	23	A
W3-N	H	4	Untreated
W4-S & E5-N	S	0	B
W4-N & E5-S[4)]	H	0	B
W5-S & E6- N	S	4	B
W5-N[4)] & E6-S	H	4[5)]	B
W6-S & E4-N	S	4	Untreated
W6-N & E4-S	H	4	A
W7-S & E7-N	S	23	B
W7-N & E7-S	H	23	B

[1)] W=western oriented, E=eastern oriented, S=southern part of element, N=northern part of element. Each element is 1,2 m wide, and each element has two panel test sections each with width 0,6 m. E.g. element E1 includes panel test sections E1-S and E1-N, see Figur 3.5.
[2)] H = fast growth rate, S = slow growth rate
[3)] A = alkyd paint (oil dilutable), B = acrylic/alkyd paint (water dispersed), ”untreated” = no surface treatment
[4)] The vertical battens were removed and the cladding mounted directed onto the windbarrier in May 2005 (i.e. from 23 mm to 0 mm air cavity)
[5)] 0 mm air gap (and no air cavity) in the period May-December 2005.

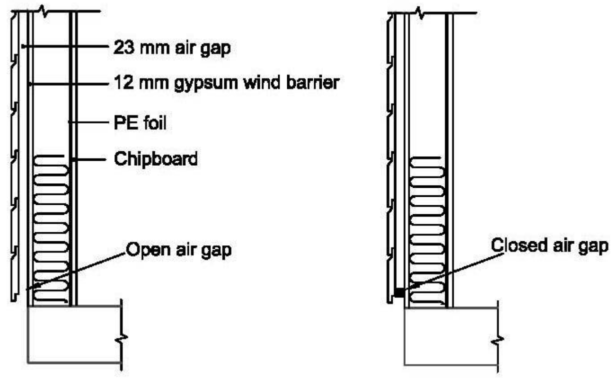

Figure 3.1
Design of air gap opening in bottom part of wall

3.3 Hygrothermal measurements

3.3.1 General

The measurements in the wall constructions started in January 2004 (testing from October 2003) and lasted till December 2005. The logging system stores hourly values. What has been measured can be summarized as follows:

- All elements have been instrumented with temperature sensors and moisture content sensors (in wood) at two different heights, respectively 1,0 m and 3,0 m from the bottom of the cladding, see Figure 3.2.
- In some elements additional measurements such as relative humidity in air gap and surface wetness have been performed. Some of these extra measurements have been performed at a different height than the standard measurements, i.e. 2,0 m from the bottom of the cladding, see Figure 3.2.
- Some elements have been equipped with gradient measurements of temperature and moisture in order to check the direction and magnitude of the heat and moisture transport, see Figure 3.4.

The locations of the sensors are shown in Figure 3.3 and 3.4. A summary of measurement sensors used for the various test sections are given in Table 3.3. The driving rain measurements on the wall sections are not included here – but are described i chapter 2.2 and Appendix 1. An overview of the measurements are also given i Figure 3.5.

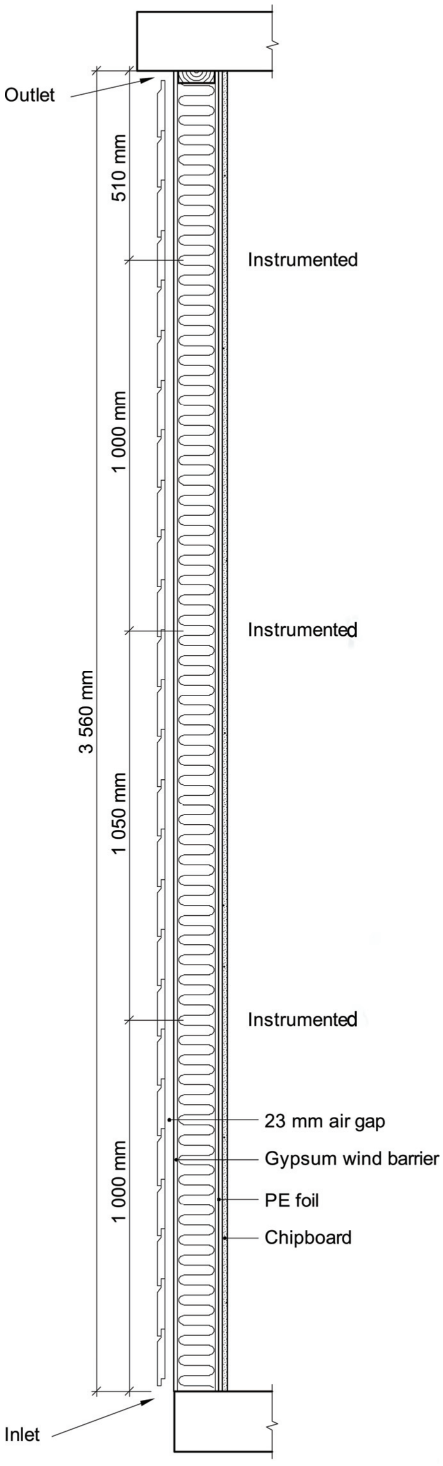

Figure 3.2
Vertical section of cladding test section

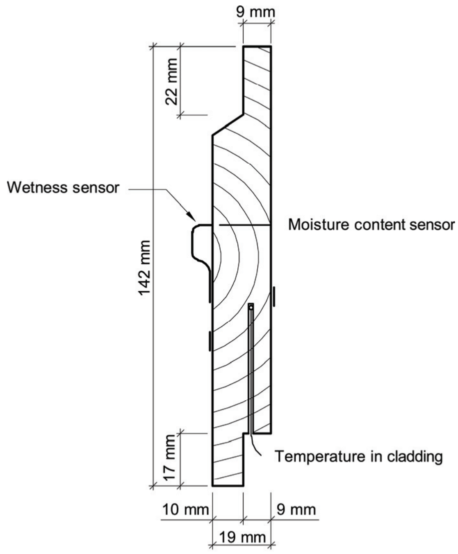

Figure 3.3
Vertical section of cladding board with temperature, moisture content and wetness sensors.

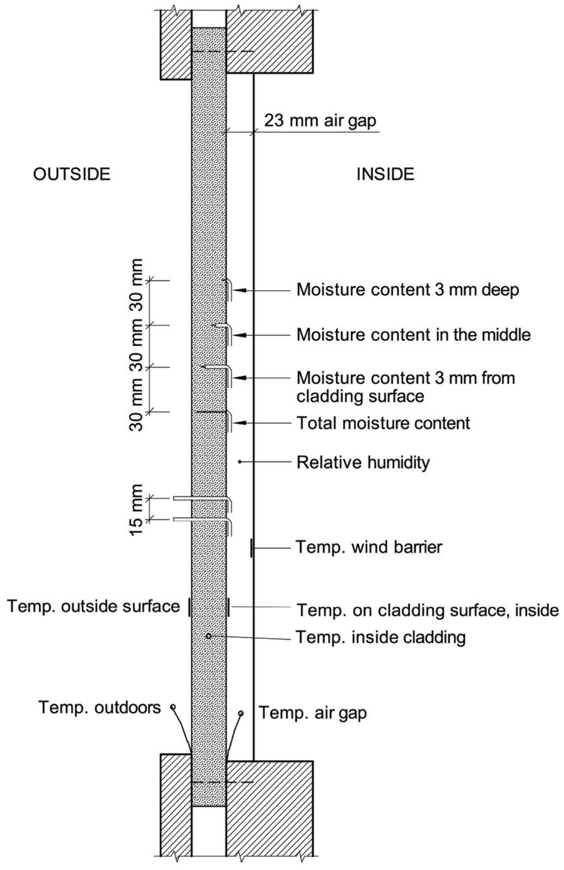

Figure 3.4
Horizontal section of test section, location of temperature, moisture content and RH sensors.

Table 3.3
Summary of hygrothermal measurement sensors in the test sections.

Sections	**Measurements and location**	**Height from bottom of wall** [1)]
Standard measurements:		
All sections	1. Temperature in the middle of cladding 2. Moisture content in cladding (uninsulated pins)	Top + bottom
Extra measurements:		
W1-N, W2-S, W2-N, E1-N, E3-N	3. Relative humidity in air gap	Middle
W2-N, W3-S, W6-N, E4-S	4. Temperature on cladding surface – inside 5. Moisture content in cladding – 3 mm from outer surface (insulated pins) 6. Moisture content in cladding – middle of cladding (insulated pins) 7. Moisture content in cladding – 3 mm from inner surface (insulated pins) 8. Surface wetness sensor (type fig. 3.8)	Top + bottom
W2-N, E4-S	9. Surface wetness sensor (type Wetcorr)	Middle
W3-S, W6-N, E4-S	10. Temperature on wind barrier surface 11. Temperature in air gap 12. Temperature on cladding surface – outside 13. Temperature of air outside section	Top + bottom
W3-S, W6-N, E4-S	14. Surface wetness sensor (type fig. 3.8)	Middle

[1)] “Bottom”, Middle” and “Top” is respectively 1,0 m, 2,0 m and 3,0 m from bottom of cladding.

a. West facing wall

b. East facing wall

Figure 3.5
Wall sections of the test house showing varied parameters and instrumentation. Figure from Nore et.al. (2005). The following codes are used:

M	moisture content sensor
T	temperature sensor
RH	relative humidity sensor in the air gap
W	surface wetness sensor
Wc	Wetcorr sensor (sensor developed by the Norwegian Air Research Institute)
A	painted with an alkyd painting (oil diluTable)
B	painted with an acryl/alkyd painting (water dispersed)

When no paint type code is given, the cladding is left untreated. Numbers 0, 4 and 23 indicate air gap openings at inlet and outlet in mm: 0 = no opening, 4 mm = small opening and 23 mm = full opening. A number given in front of sensor type indicates that the gradient is being measured as shown in Figure 3.4.

3.3.2 Temperature and relative humidity

Temperatures are measured by a compensation cable and thermo element copper/constantan, type T. The temperature measurement accuracy is ± 0,5°C in the temperature range [-59, 93 °C]. The temperature is measured by comparing to reference resistances.

Temperature of the air outside of the cladding (# 13, Table 3.3) are shielded from radiation effects so as to measure the exact air temperature, see Figure 3.6.

Figure 3.6
Temperature sensor for outdoor air directly outside of the cladding.

3.3.3 Moisture content in wood

The moisture content of wooden claddings was measured by traditional pin electrode resistance measurements. The measurements are adjusted according to wood species and temperature. The measurement range is normally set to 7-25 % by weight. The accuracy of resistance measurements are discussed in Apneseth and Hay (1992). The measurement accuracy depends generally on three factors:

- systematic errors in the measurement apparatus
- material related measurement errors (i.e. there are not 100% correlation between resistance and moisture content)
- accidental errors

For our measurements we neglect the effect of systematic errors in the measurement apparatus and logging system. The material related errors varies with wood species, and increases with increasing moisture content. In Du et.al. (1991) the following 95% confidence interval ($\pm 1{,}96\cdot\sigma$) was found for one single measurement on spruce:

Table 3.4
Measurement uncertainty for resistance measurements on spruce (Du et.al., 1991).

Wood moisture content (weight%):	**7%**	**12%**	**18%**	**25%**
95% confidence interval ($\pm 1{,}96\cdot\sigma$):	± 0,37	± 0,65	± 1,21	± 2,09

The measurement method with the given electrode setup and measurement sequence as described below was controlled in Geving and Uvsløkk (2000) by the gravimetric method. The gravimetric measurements showed very good accordance with the resistance measurements, well within the 95% confidence interval showed in table 3.4.

The distance between the two steel pins was 25 mm. The diameter of the metal electrodes used was 2 mm. The sensors meant to measure at a specific depth in the cladding (#5, 6 and 7, see Table 3.3) were covered with 0.5 mm plastic except for 3 mm at the tip. The standard measurement sensor (#2) were not covered by plastic, and intruded from the back of the cladding till 3 mm from the external surface. This means that this sensor will measure the highest moisture content in the cladding.

The measurement sequence was as follows:

1. The measurement output (voltage) was converted to moisture content using the converter Delmhorst MT(G) 40. The converter employs the following calibration curve:
$$u_0 = -0{,}5\cdot U^4 + 3{,}6212\cdot U^3 - 5{,}1551\cdot U^2 - 15{,}53\cdot U + 40{,}172$$
where u_0 is moisture content (weight%) not compensated for temperature and wood species and U is the output voltage (V).

2. u_0 is then compensated for temperature with the following formula:
$$u_1 = \frac{u_0 + 0{,}567 - [0{,}026\cdot(t+2{,}8)] + [0{,}000051\cdot(t+2{,}8)^2]}{0{,}881\cdot 1{,}0056^{t+2{,}8}} * 1{,}099 - 0{,}319$$
where u_1 is moisture content corrected for temperature t (°C).

3. u_1 is then compensated for wood species, i.e. in this case spruce:
$$u = -1{,}5476 + 1{,}5986\cdot u_1 - 0{,}01023\cdot u_1^{\,2} - 0{,}001233\cdot u_1^{\,3} + 0{,}000045\cdot u_1^{\,4}$$
where u is the corrected moisture content.

3.3.4 Time of wetness

To assess the period of time the external surface experiences liquid water on the surface two different type of sensors were used. Both were used merely to assess the on-set and off-set of a water film on the surface. The Wetcorr sensor is a commercially available sensor.

The other type of sensor is merely an ordinary pin electrode resistance sensor, where the tip of the electrode is placed in contact with the external surface of the cladding – but not intruding the surface, see Figure 3.7. The measurement sequence is as described in chapter 3.3.3. When the surface is dry a very low moisture content is measured, but when a film of water has developed a very high moisture content is read.

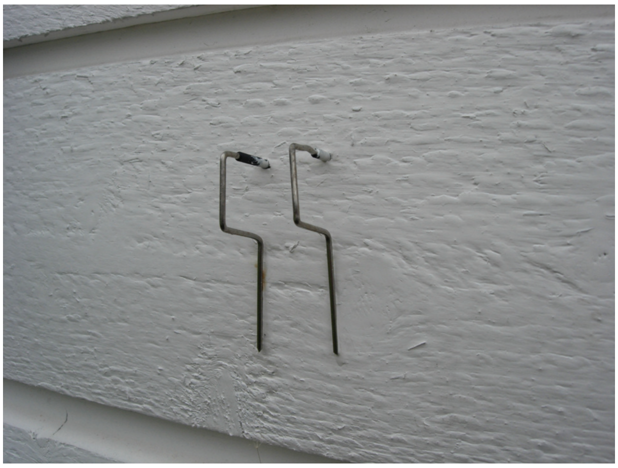

Figure 3.7
The pin electrode resistance sensor used as surface wetness sensor.

4 Results

4.1 Weather data

4.1.1 Ordinary weather data

Statistical weather data from Voll AWS are given in Table 4.1 and Figures 4.1-4.5. Week no. 1 starts 1. January 2004.

Table 4.1
Yearly averages of temperature (TTM), relative humidity (UUM) and vertical precipitation (RR) from Voll AWS.

År	TTM (^{o}C)	UUM (%)	RR (mm)
2004	6,2	71,9	985
2005	6,2	73,0	817

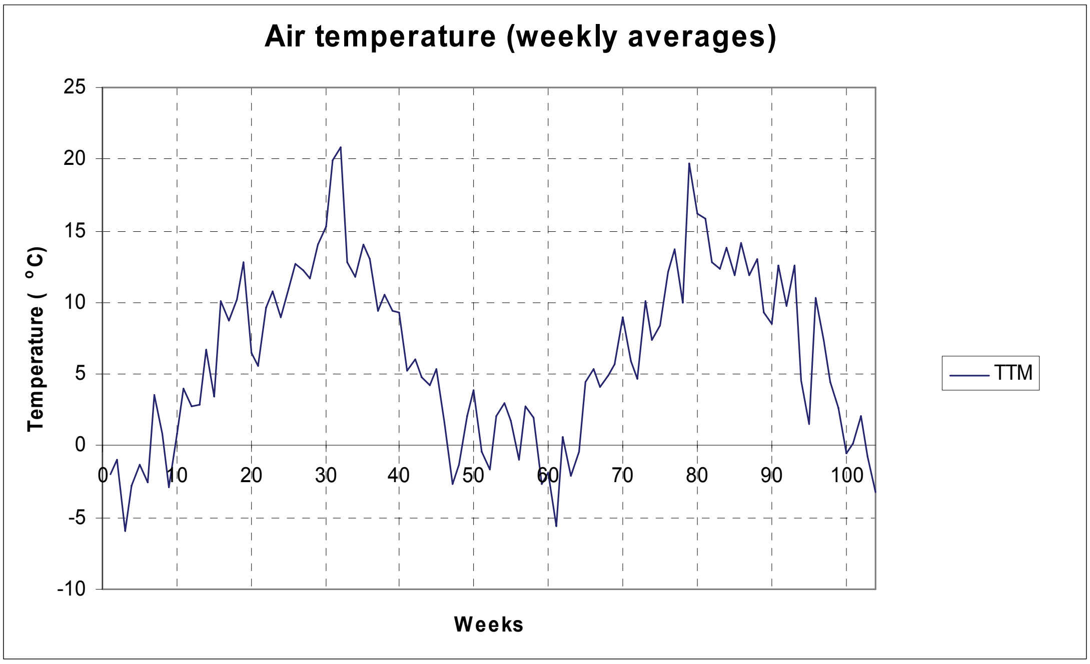

Figure 4.1
Air temperature (weekly averages) from Voll AWS.

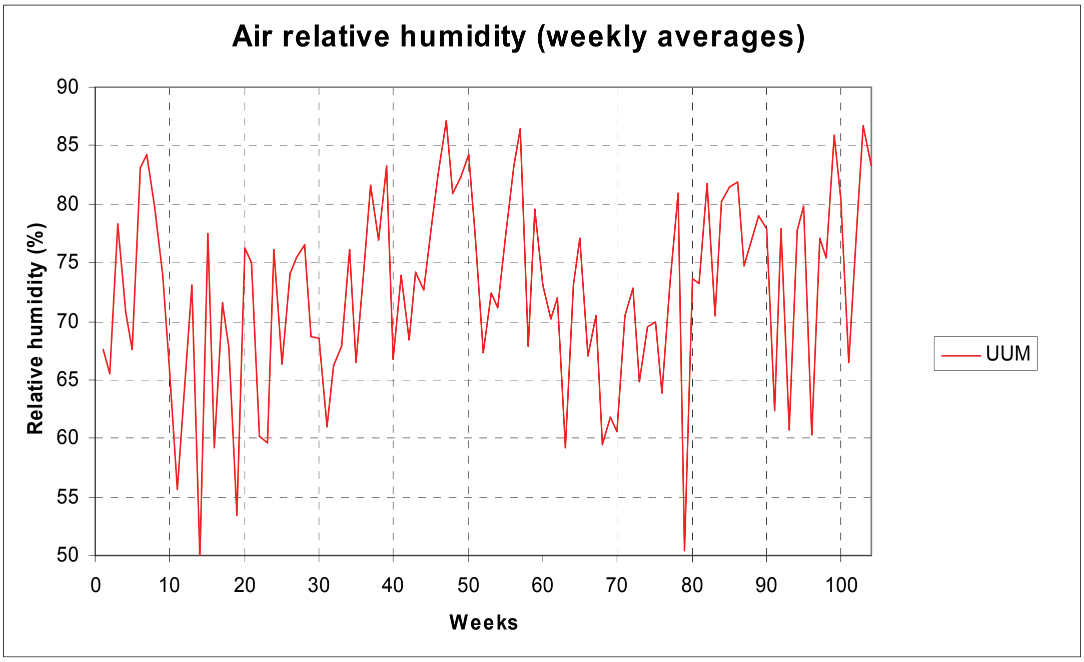

Figure 4.2
Air relative humidity (weekly averages) from Voll AWS.

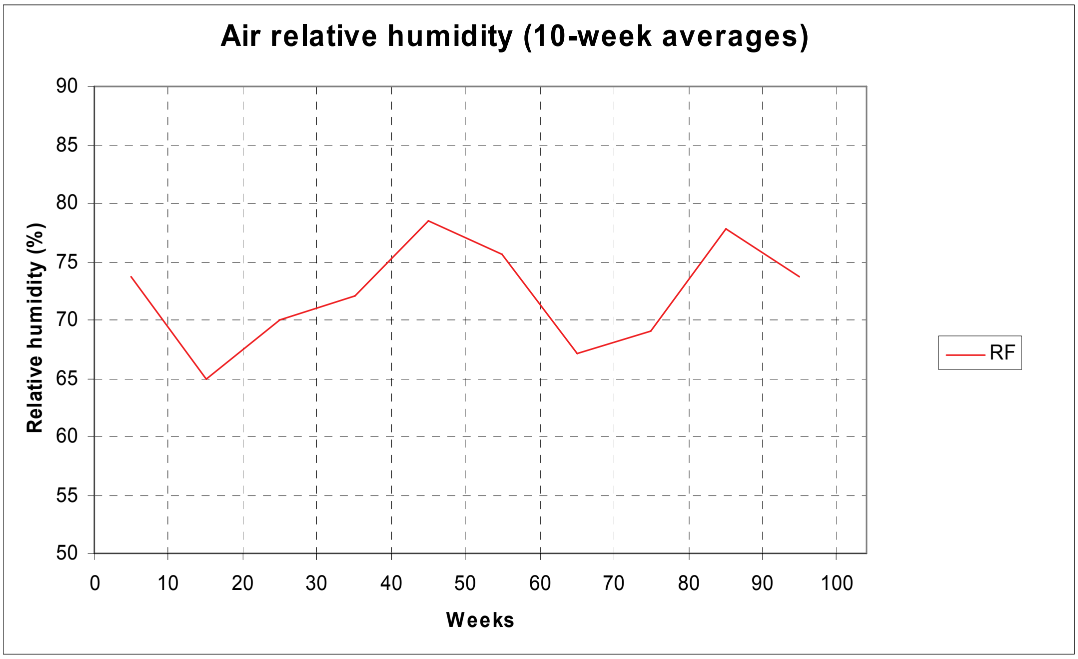

Figure 4.3
Air relative humidity from Voll AWS. The values given are 10-week averages to show the seasonal variation.

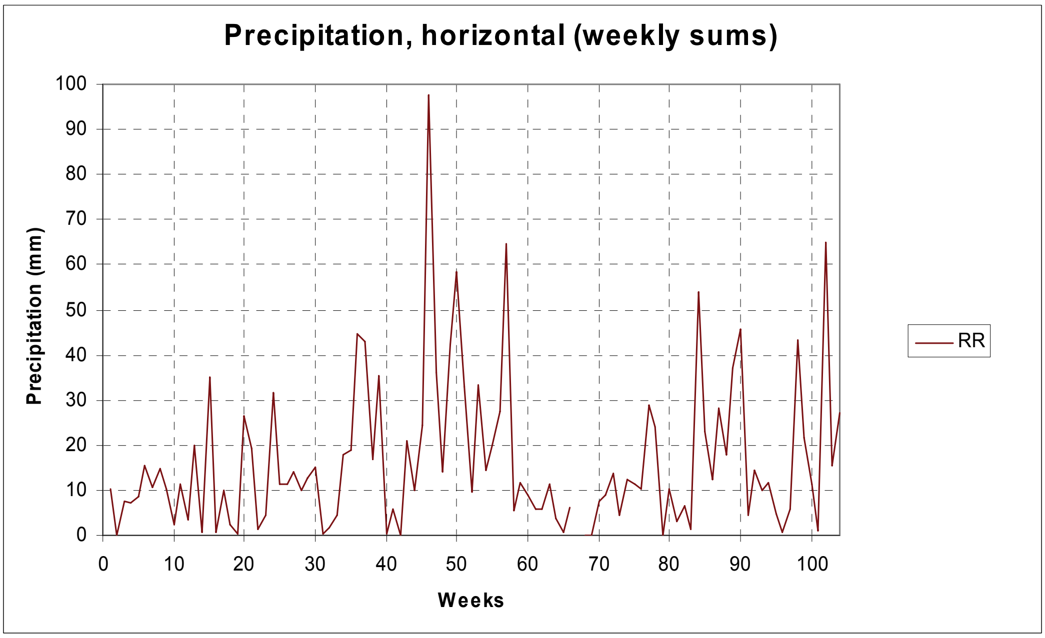

Figure 4.4
Horizontal precipitation, rain and snow (weekly sums) from Voll AWS.

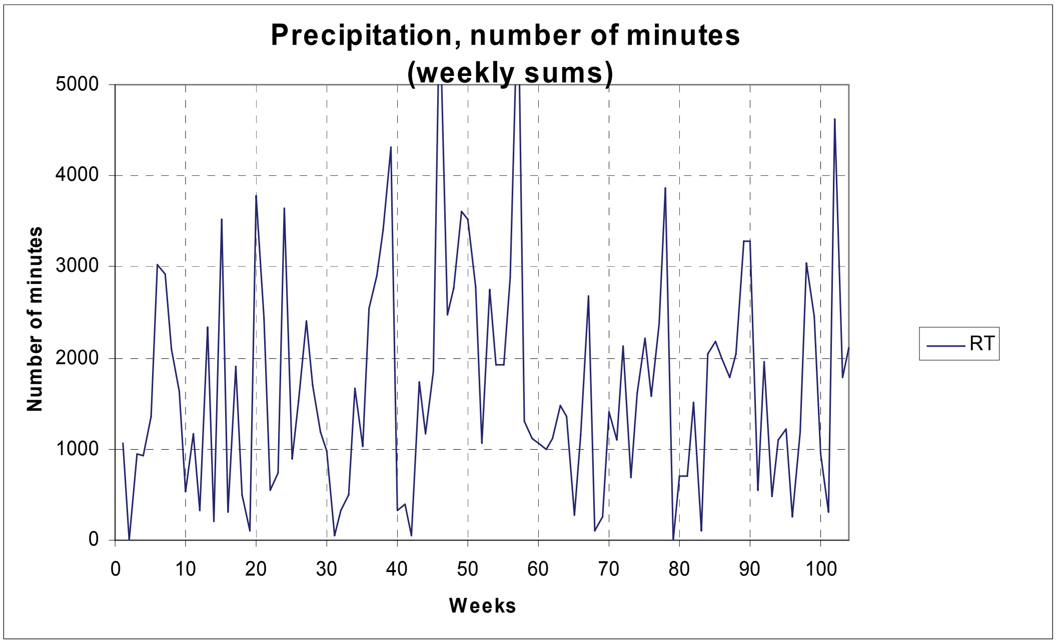

Figure 4.5
Number of minutes of precipitation (weekly sums) from Voll AWS. For comparison there are 10080 minutes in a week.

4.1.2 Driving rain data

Driving rain data from the free field directional driving rain gauge are given in Figure 4.6. It should be noted that this also includes snow. In Figure 4.7 driving rain data from the wall mounted driving rain gauges are shown. Additional information are shown in Appendix 4 (case 37 – 40). A more thorough analysis of the driving rain data are given in Nore, Blocken, Jelle, Thue and Carmeliet (2006).

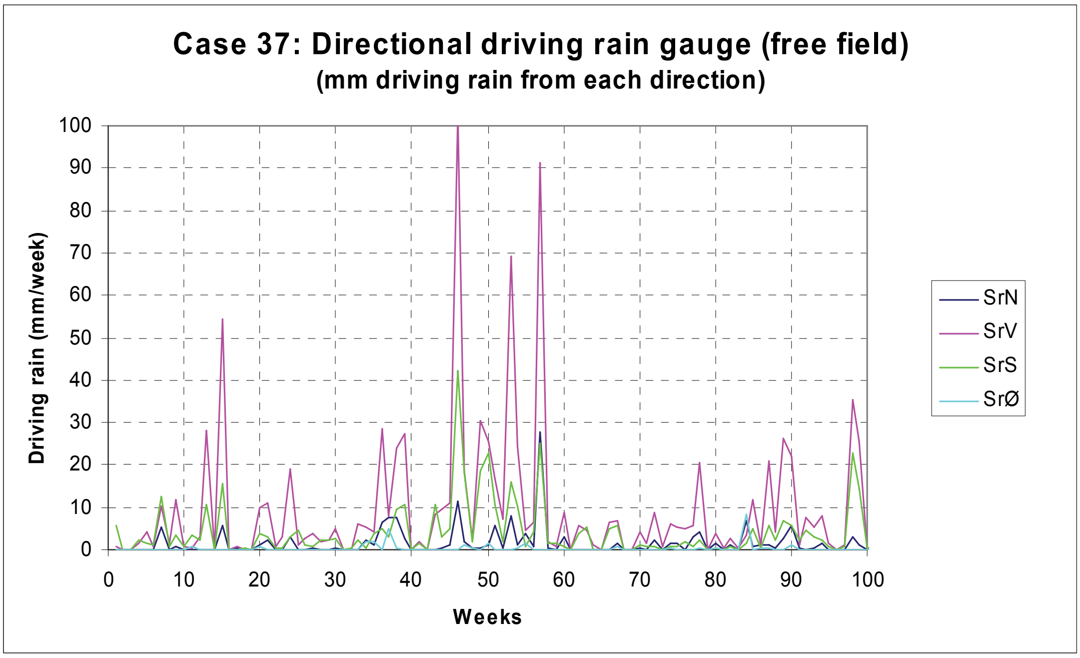

Figure 4.6
Free field driving rain mesaurements in four directions; from north (SrN), west (SrV), south (SrS) and east (SrE).

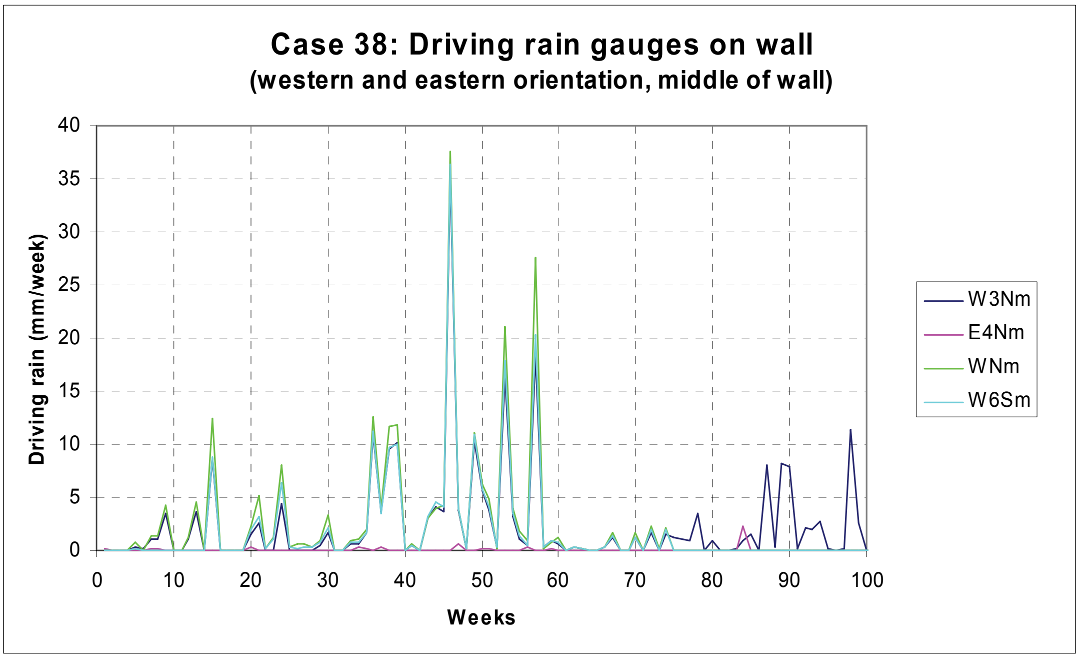

Figure 4.7
Driving rain measurements from wall mounted gauges in the middle part of four wall elements. Data for WNm and W6Sm are missing after week no 75. Generaly we find almost similar values for all the gauges on western elements.

4.2 Hygrothermal measurements on claddings

4.2.1 Graphical presentation of results (weekly averages)

The main analysis was made on grapical output of weekly averages of measured values. To see a possible effect of the investigated parameters, various comparisons between different elements and measurement locations were done. In Table A4.1 in appendix 4 an overview of the various comparative cases is given. All the cases are shown in appendix 4, Case 1-46. Some of these Figures are also shown in chapter 5, but for a full overview we refer to the appendix.

4.2.2 Statistical data

Statistical data for the moisture content in the cladding (uninsulated pins) are given for every section in Table 4.2 and 4.3.

To assess the risk of decay and mould growth a mould growth potential called "Max-days" have been calculated. The mould growth potential includes the effect of both the temperature and moisture content during a one year period from summer 2004 to summer 2005 (week 26-78). The higher the value the bigger the risk for mould growth. The calculation of this potential are explained i appendix 3.

Table 4.2 Statistical data for the **moisture content** in the cladding (weight-%, uninsulated pins) for all **western** sections.

Section	Description (see Tab. 3.2 and Fig. 3.5)	Average 2004-2005	Average 2004	Average 2005	Average winter (Dec 2004-Feb 2005)	Average summer (Jun 2005-Aug 2005)	Max weekly winter (Dec 2004 –Feb 2005)	Max weekly summer (Jun 2005 –Aug 2005)	Min weekly summer 2005 (Jun 2005-Aug 2005)	Mould growth potential (sum of "Max-days" week 26-78)
W1S-d	H 0 A	18,5	18,4	18,7	21,9	16,1	22,6	17,5	14,7	3,1
W1S-u *	H 0 A	17,9	16,1	19,7	23,8	17,6	29,0	19,4	15,5	5,7
W1N-d	S 0 A	18,0	18,1	18,0	21,1	15,8	22,1	16,8	14,7	2,0
W1N-u	S 0 A	19,8	19,6	19,9	22,7	18,1	23,6	19,5	17,0	6,6
W2S-d	S 4 A	17,7	18,0	17,4	20,9	15,3	21,7	16,4	14,3	1,7
W2S-u	S 4 A	18,3	18,4	18,2	20,5	16,7	21,4	17,9	15,4	2,3
W2N-d	S 23 A	20,0	18,3	21,7	20,7	16,3	21,9	17,8	14,8	2,2
W2N-u	S 23 A	18,1	18,1	18,1	20,5	16,6	21,6	18,3	14,8	2,0
W3S-d	H 23 A	17,4	17,6	17,2	20,0	15,4	21,3	17,0	13,6	1,5
W3S-m	H 23 A	18,1	17,4	18,9	19,9	15,3	21,0	16,9	13,5	2,7
W3S-u	H 23 A	17,7	17,7	17,6	20,2	15,9	21,5	17,8	13,5	1,7
W3N-d	H 4 Untreated	17,0	17,8	16,2	22,1	13,0	27,0	15,4	9,8	3,9
W3N-u	H 4 Untreated	17,7	18,0	17,5	22,7	14,6	27,7	17,2	10,6	4,7
W4S-d	S 0 B	18,8	19,9	17,7	22,2	14,5	22,7	15,4	13,4	3,1
W4S-u	S 0 B	19,4	20,0	18,8	21,7	16,8	22,3	17,8	15,6	4,7
W4N-d	H 0 B	18,2	19,5	16,8	21,8	14,2	22,5	15,3	13,1	2,7
W4N-u	H 0 B	19,6	20,3	18,9	22,3	16,5	23,1	17,6	15,2	4,9
W5S-d	S 4 B	17,7	18,6	16,8	21,1	13,9	22,5	15,4	12,8	2,6
W5S-u	S 4 B	18,4	18,6	18,1	20,8	16,3	22,0	18,2	14,5	2,6
W5N-d	H 4/0 B	17,5	18,5	16,4	21,1	13,3	22,6	14,7	12,3	2,5
W5N-u	H 4/0 B	17,8	18,3	17,3	20,5	15,3	21,8	16,8	13,8	2,2
W6S-d	S 4 Untreated	17,7	18,7	16,6	23,4	13,3	29,2	15,1	11,0	5,2
W6S-u	S 4 Untreated	17,1	17,6	16,7	21,5	14,1	24,9	16,3	11,1	3,0
W6N-d	H 4 A	18,4	18,6	18,2	22,1	15,9	23,1	17,4	14,3	3,2
W6N-m	H 4 A	17,8	18,0	17,6	20,6	15,7	21,7	17,0	14,0	1,9
W6N-u	H 4 A	18,3	18,5	18,1	21,7	15,9	23,4	17,7	13,7	3,1
W7S-d	S 23 B	17,4	18,0	16,9	20,3	14,8	21,6	16,4	13,4	1,7
W7S-u	S 23 B	18,2	18,4	18,1	20,9	16,5	22,2	17,7	14,6	2,6
W7N-d	H 23 B	18,1	18,7	17,4	21,2	15,2	22,8	17,1	13,6	2,9
W7N-u	H 23 B	18,1	18,2	18,1	20,7	16,5	22,4	19,0	13,7	2,2

* The measurements for W1-S u/M seems to bee wrong for the period week 0-50. I.e. the values that are marked gray in this table are probably wrong.

Table 4.3 Statistical data for the **moisture content** in the cladding (weight-%, uninsulated pins) for all **eastern** sections

Section	Description (see Tab. 3.2 and Fig. 3.5)	Average 2004-2005	Average 2004	Average 2005	Average winter (Dec 2004-Feb 2005)	Average summer (Jun 2005-Aug 2005)	Max weekly winter (Dec 2004 –Feb 2005)	Max weekly summer (Jun 2005 –Aug 2005)	Min weekly summer 2005 (Jun 2005-Aug 2005)	Mould growth potential (sum of "Max-days" week 26-78)
E1S-d	H 0 A	16,3	16,5	16,2	18,1	14,7	18,6	16,1	12,8	0,3
E1S-u	H 0 A	16,5	16,5	16,4	18,4	14,7	18,8	16,0	13,4	0,4
E1N-d	S 0 A	16,7	16,8	16,6	17,9	15,4	18,2	16,2	14,4	0,3
E1N-u	S 0 A	16,9	16,9	16,8	18,1	15,7	18,4	16,4	14,7	0,4
E2S-d	H 0 A	17,3	17,4	17,3	19,5	15,5	20,2	17,6	13,3	1,2
E2S-u	H 0 A	16,9	17,0	16,8	18,7	15,2	19,1	16,4	13,7	0,6
E2N-d	S 4 A	17,4	17,4	17,4	19,4	15,8	19,9	17,0	14,7	1,0
E2N-u	S 4 A	17,2	17,2	17,3	19,1	15,8	19,7	17,1	14,5	0,9
E3S-d	H 23 A	18,1	18,2	17,9	20,1	16,2	21,2	18,4	13,9	2,0
E3S-u	H 23 A	17,1	17,1	17,2	19,1	15,4	19,9	17,2	13,6	0,9
E3N-d	S 23 A	17,4	17,4	17,4	19,1	16,0	19,8	17,6	14,5	1,0
E3N-u	S 23 A	17,0	16,9	17,0	18,8	15,6	19,5	17,2	14,1	0,7
E4S-d	H 4 A	16,2	16,4	16,0	17,9	14,4	18,6	16,1	12,7	0,2
E4S-m	H 4 A	16,7	16,9	16,6	18,7	14,8	19,5	16,7	13,0	0,6
E4S-u	H 4 A	15,8	16,0	15,7	17,8	13,9	18,4	15,7	12,3	0,2
E4N-d	S 4 Untreated	17,8	17,8	17,9	20,5	15,6	22,2	19,5	12,3	2,3
E4N-u	S 4 Untreated	16,7	16,6	16,7	19,1	14,6	20,4	17,4	11,8	0,8
E5S-d	H 0 B	16,5	17,4	15,6	18,1	13,6	19,7	16,6	11,8	0,5
E5S-u	H 0 B	17,1	17,2	17,0	18,7	15,2	19,9	17,3	13,3	0,6
E5N-d	S 0 B	17,3	18,1	16,5	19,1	14,4	20,0	16,7	12,9	1,1
E5N-u	S 0 B	17,2	17,4	17,0	18,7	15,2	19,3	16,9	13,7	0,7
E6S-d	H 4 B	17,4	17,7	17,1	19,3	15,4	20,3	17,2	14,1	1,1
E6S-u	H 4 B	17,4	17,5	17,3	19,6	15,4	20,4	17,2	14,1	1,4
E6N-d	S 4 B	17,3	17,5	17,0	19,1	15,2	19,8	17,2	13,6	0,9
E6N-u	S 4 B	16,4	16,5	16,4	18,4	14,6	19,2	16,5	12,8	0,5
E7S-d	H 23 B	18,0	18,1	17,8	20,1	16,0	21,6	18,8	12,7	2,0
E7S-u	H 23 B	17,6	17,6	17,6	19,7	15,9	20,7	18,2	13,6	1,5
E7N-d	S 23 B	17,4	17,7	17,0	19,5	15,2	20,5	17,6	13,4	1,2
E7N-u	S 23 B	16,9	16,8	16,9	19,0	15,2	19,7	17,3	13,3	0,7

4.2.3 Comparative data

To investigate the effect of the various wall configuration we focuses on the mould growth potential (“Max-days”) calculated in chapter 4.3.2. For two configurations (sections) where only one parameter differs we calculate a dimensionless quotient, which is the “Max-days” of one section divided by the “Max-days” of the other section. If we for instance divide the “Max-days” of section W1-S with W3-S we get a quotient of 4,4/2,0 = 2,2. Since the only parameter separating these two sections is the thickness of the air gap opening (W1-S has 0 mm and W7-N has 23 mm) we get an indication that the risk for mould growth is higher when the panel is not ventilated. Such comparisions are given in Table 4.4-4.8. In all the tables in this chapter except Table 4.5 the average of the top and bottom value is used.

Table 4.4
Effect of ventilation gap opening

Section 1 / section 2	Description	Comparative parameters	Quotient Max-days1/Max-days 2
W1S / W3S	H 0 A / H 23 A	0 mm/ 23 mm	1,9*
W1N / W2N	S 0 A / S 23 A	0 mm/ 23 mm	2,0
W4S / W7S	S 0 B / S 23 B	0 mm/ 23 mm	1,8
W4N / W7N	H 0 B / H 23 B	0 mm/ 23 mm	1,5
E1S / E3S	H 0 A / H 23 A	0 mm/ 23 mm	0,23
E1N / E3N	S 0 A / S 23 A	0 mm/ 23 mm	0,41
E5N / E7N	S 0 B / S 23 B	0 mm/ 23 mm	0,94
W2S / W2N	S 4 A / S 23 A	4 mm/ 23 mm	0,95
W5S / W7S	S 4 B / S 23 B	4 mm/ 23 mm	1,2
W6N / W3S	H 4 A / H 23 A	4 mm/ 23 mm	1,4
E2N / E3N	S 4 A / S 23 A	4 mm/ 23 mm	1,1
E6N / E7N	S 4 B / S 23 B	4 mm/ 23 mm	0,74
E4S / E3S	H 4 A / H 23 A	4 mm/ 23 mm	0,22

* The value for W1-S u/M is not included due to measurement errors.

Table 4.5
Variation of MC with height of wall

Section	Description	Comparative parameters	Quotient Max-days1/Max-days 2
W1N	S 0 A	Bottom /Top	0,30
W2S	S 4 A	Bottom /Top	0,74
W2N	S 23 A	Bottom /Top	1,1
W3S	H 23 A	Bottom /Top	0,88
W3N	H 4 Untreated	Bottom /Top	0,83
W4S	S 0 B	Bottom /Top	0,66
W4N	H 0 B	Bottom /Top	0,55
W5S	S 4 B	Bottom /Top	1,0
W5N	H 4/0 B	Bottom /Top	1,1
W6S	S 4 Untreated	Bottom /Top	1,7
W6N	H 4 A	Bottom /Top	1,0
W7S	S 23 B	Bottom /Top	0,65
W7N	H 23 B	Bottom /Top	1,3
E1S	H 0 A	Bottom /Top	0,75
E1N	S 0 A	Bottom /Top	0,75
E2S	H 0 A	Bottom /Top	2
E2N	S 4 A	Bottom /Top	1,1
E3S	H 23 A	Bottom /Top	2,2
E3N	S 23 A	Bottom /Top	1,4
E4S	H 4 A	Bottom /Top	1,0
E4N	S 4 Untreated	Bottom /Top	2,9
E5S	H 0 B	Bottom /Top	0,83
E5N	S 0 B	Bottom /Top	1,6
E6S	H 4 B	Bottom /Top	0,79
E6N	S 4 B	Bottom /Top	1,8
E7S	H 23 B	Bottom /Top	1,3
E7N	S 23 B	Bottom /Top	1,7

Table 4.6
Effect of surface treatment

Section 1 / section 2	Description	Comparative parameters	Quotient Max-days1/Max-days 2
W1S / W4N	H 0 A / H 0 B	Oil based/water based	0,82*
W1N / W4S	S 0 A / S 0 B	Oil based/Water based	1,1
W2S / W5S	S 4 A / S 4 B	Oil based/Water based	0,77
W2N / W7S	S 23 A / S 23 B	Oil based/Water based	0,95
W3S / W7N	H 23 A / H 23 B	Oil based/Water based	0,77
E1N / E5N	S 0 A / S 0 B	Oil based/Water based	0,39
E2N / E6N	S 4 A / S 4 B	Oil based/Water based	1,4
E3N / E7N	S 23 A / S 23 B	Oil based/Water based	0,89
E3S / E7S	H 23 A / H 23 B	Oil based/Water based	0,83
E4S / E6S	H 4 A / H 4 B	Oil based/Water based	0,25
W6N / W3N	H 4 A / H 4 Untreated	Oil based/Untreated	0,63
W2S / W6S	S 4 A / S 4 Untreated	Oil based/Untreated	0,49
E2N / E4N	S 4 A / S 4 Untreated	Oil based/Untreated	0,59

* The value for W1-S u/M is not included due to measurement errors.

Table 4.7
Effect of driving rain exposure (orientation). “Western” gives high driving rain exposure while “Eastern” gives low driving rain exposure.

Section 1 / section 2	Description	Comparative parameters	Quotient Max-days1/Max-days 2
W1S / E1S	H 0 A	Western/Eastern	8,9*
W1N / E1N	S 0 A	Western/Eastern	12
W2S / E2N	S 4 A	Western/Eastern	2,1
W2N / E3N	S 23 A	Western/Eastern	2,5
W3S / E3S	H 23 A	Western/Eastern	1,3
W4S / E5N	S 0 B	Western/Eastern	4,3
W5S / E6N	S 4 B	Western/Eastern	3,7
W6S / E4N	S 4 Untreated	Western/Eastern	2,6
W6N / E4S	H 4 A	Western/Eastern	8,2
W7S / E7N	S 23 B	Western/Eastern	2,3
W7N / E7S	H 23 B	Western/Eastern	1,4

* The value for W1-S u/M is not included due to measurement errors.

Table 4.8
Effect of growth rate of wood

Section 1 / section 2	Description	Comparative parameters	Quotient Max-days1/Max-days 2
W1S / W1N	H 0 A / S 0 A	Fast grown/ Slow grown	0,72*
W6N / W2S	H 4 A / S 4 A	Fast grown/ Slow grown	1,4
W3S / W2N	H 23 A / S 23 A	Fast grown/ Slow grown	0,95
W4N / W4S	H 0 B / S 0 B	Fast grown/ Slow grown	0,97
W7N / W7S	H 23 B / S 23 B	Fast grown/ Slow grown	1,2
W3N / W6S	H 4 Untreated / S 4 Untreated	Fast grown/ Slow grown	1,0
E1S / E1N	H 0 A / S 0 A	Fast grown/ Slow grown	1,0
E4S / E2N	H 4 A / S 4 A	Fast grown/ Slow grown	0,35
E3S / E3N	H 23 A / S 23 A	Fast grown/ Slow grown	1,8
E6S / E6N	H 4 B / S 4 B	Fast grown/ Slow grown	1,9
E7S / E7N	H 23 B / S 23 B	Fast grown/ Slow grown	1,9

* The value for W1-S u/M is not included due to measurement errors.

5 Discussion

5.1 Overall limitations of the experiments

The experiments are conducted for one specific climate, and some of the results could have been different at other climates. Trondheim has a coastal climate with relatively mild winters, but is not particularly exposed in regard to driving rain. In a Norwegian context the rain exposure in Trondheim would be regarded at an average level. Thus the inland of Norway will typically experience colder winters and generally less rain, while the more exposed coastal areas (e.g. the more western parts of Norway) will have more rain and slightly higher winter temperatures.

In regard to the construction and cladding configuration the following facts should be kept in mind;

- The timber frame sections are built to be very airtight (good workmanship and no perforation of barriers). In real life one should expect local air leakages transporting indoor air humidity out into the upper part of the wall sections. Such air leakages, and especially if the indoor air humidity is generally high, may have a considerable effect on for instance an unventilated cladding. There is no moisture production inside of the test house.
- The chosen cladding configuration is relatively airtight. Some other cladding configurations would definitely be less airtight, and thus be less dependant on the air gap openings in regard of ventilation. On the other hand, such claddings would probably have a lower resistance to rain penetration, and will therefore need a higher level of ventilation.
- The height of the air gap influences on the air speed and thus the ventilation rate of the air gap
- Several factors may affect the temperature of the cladding and thus the moisture content, such as the size of the roof eaves (medium size), colour of the cladding (white) and insulation thickness of the construction (150 mm).
- Several factors may affect the amount of driving rain hitting the facade and thus the moisture content of the cladding, such as the size of the roof eaves (relatively small) and the height of the building (low).
- Weathering of the surface treatment, cracking of the wooden cladding etc. may affect the long term moisture performance. The measurements are performed during the two first years of the claddings service life, i.e. a 10 years old cladding/paint may behave different.
- The test house has a flat roof while most buildings with wooden panels have ventilated sloped roof. The wind pressure at the roof eaves are different for these two types of roofs and thereby the wind induced ventilation of the facade cladding.

5.2 General observations

Over the year the moisture content shows considerably seasonal variations, with highest MC during winter (peak in December-February) and lowest in the summer (June-August). The seasonal drying of the cladding seems to start approximately in March, while the MC starts to increase approximately in September. When looking at all the elements the MC varies within the region 12-28 weight% (weekly averages), see Figures 5.1 and 5.2. During the winter period (December-February) the MC varies between 17-28 weight%, and during summer (June-August) between 13-18 weight%. The variation is larger for the western sections than for the eastern sections.

The seasonal variation of MC may be caused by several factors such as:

- There are higher amounts of driving rain during autumn/winter than during summer, see Figure 4.6.
- There is a seasonal variation of RH in the air (see Figure 4.3 and 5.1) that coincides with the seasonal variation in MC.
- Lower air temperatures during winter gives a lower potential for drying after wetting of the panels by rain. The vapour concentration difference between a wet panel and the air is generally increasing with increasing temperature. This means that the moisture transport potential is higher during the summer.
- Higher levels of solar radiation during summer than winter give higher temperature difference between the panels and the air. Thus the potential for drying of panels are higher during summer.

When comparing the RH of the air (see seasonal variations in Figure 4.3) with sorption isotherms for spruce we find that the expected level of MC coincides rather good with the MC of the eastern sections. In Figure 4.3 we find the lowest 10-weeks average to be 65% RH (summer) and the highest 10-weeks average to be 78% (winter). 65% RH on the sorption isotherm for spruce at 20 ^{o}C (see e.g. Figure A3.1 in Appendix 3)) gives approximately 13 weight% MC, while 78% gives approx. 17 weight% MC. If we correct the winter value due to a lower temperature (sorption isotherm is higher at lower temperatures) we get that 78% RH (at 0^{o}C) equals approximately 18,5 weight%.

There are a number of peaks on the MC-curves during the year. These periods of increased MC are caused by prolonged periods with wet weather (rain, high RH, little solar radiation).

Condensation on the external surfaces may also have an effect on both the level of the MC and the seasonal variation, especially for the east facing side. This was investigated for this test house in Nore, Thue and Rydock (2006). It was found that the number of hours with surface condensation (calculated from measured dewpoint temperature of the air and surface temperature) on the east facing side was almost three times that of the west facing side. The number of hours with surface condensation on the east facing side (303 hours at bottom of wall) was almost the same as the number of hours with wind driven rain on the eastern side (385 hours at bottom of wall). The number of hours with surface condensation at the top of the wall was considerably less that at the bottom (e.g. 130 hours at top of wall versus 303 hours at bottom, for eastern side).

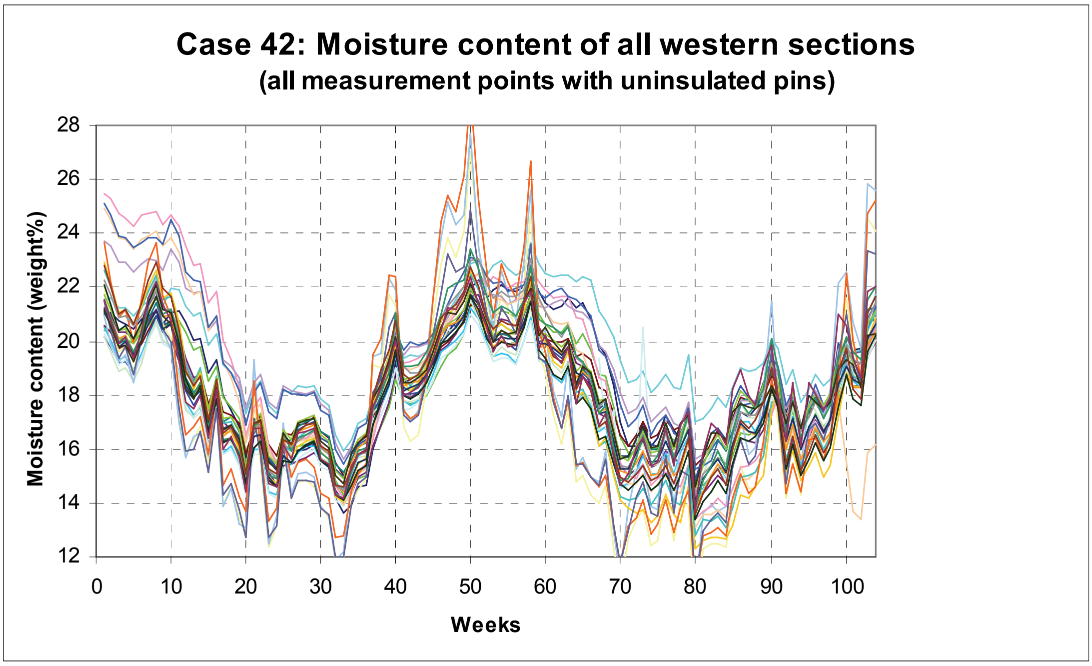

Figure 5.1

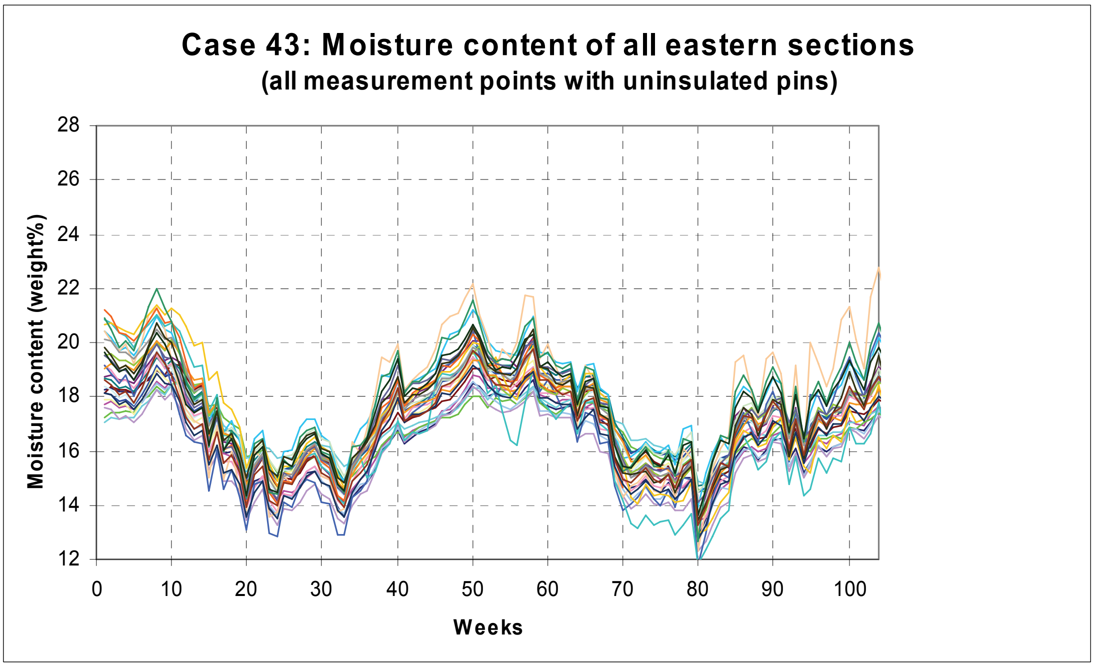

Figure 5.2

5.3 Effect of ventilation gap opening

5.3.1 Little driving rain exposure

We observe that for eastern orientation (less driving rain) the MC is significantly lower (approx. 1 weight%) during winter season for elements with no air gap opening, compared with both 4 mm and 23 mm opening (see case 1 and 2 in Appendix 4, Figure 5.3 and Table 4.3. This is probably partly due to the fact that with no ventilation the cladding will have a higher temperature than the ventilated cladding, see chapter 5.9. Since there are less rain hitting the cladding and negligible vapour diffusion and air leakages from the interior, this higher temperature yields better drying conditions and a lower RH in the cladding than for the ambient outdoor air.

The same cases also show relatively little difference of MC between 4 and 23 mm air gap opening. When considering the fact that the lowest MC was obtained with no air gap opening one might have expected 23 mm opening giving the highest MC during winter – but this was not generally the case.

The findings above is confirmed when we control the calculated mould growth potential "Maxdays" in Table 4.4. For eastern orientation we find that the mould growth potential is considerable less for 0 mm air gap opening compared with 23 mm opening. When comparing the mould growth potential for 4 and 23 mm air gap openings we find no clear difference, but there may be indications of lower mould growth potential for the 4 mm air gap opening.

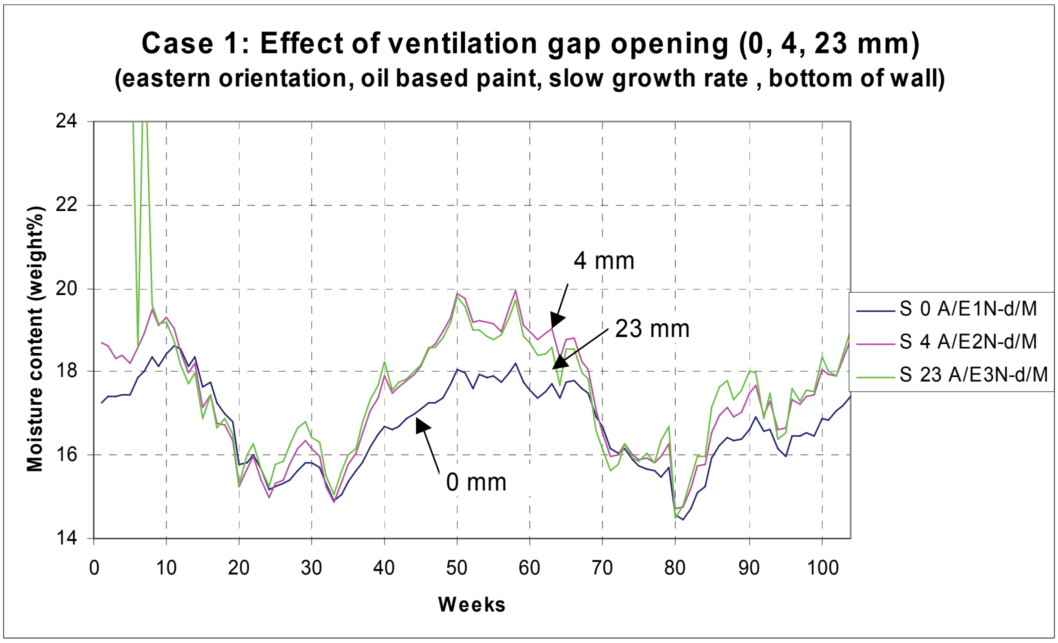

Figure 5.3

5.3.2 High driving rain exposure

For the western orientation (high driving rain exposure) we observe the opposite effect than for the eastern orientation (see cases 3-8). The MC is significantly higher with no air gap opening compared with 4 and 23 mm air gap opening (approx 23 weight% during winter), see Figure 5.4 and Table 4.2. This is probably due to the uptake of rain water, where a ventilated air gap gives better drying conditions for the cladding after a rainy period.

It is however interesting to observe that the difference in MC between 4 and 23 mm air gap opening do not show a clear tendency. In periods the 23 mm air gap opening give the lowest MC, but in other periods the 4 mm openings give the lowest MC. Generally the difference is small (usually < 0,5 weight%).

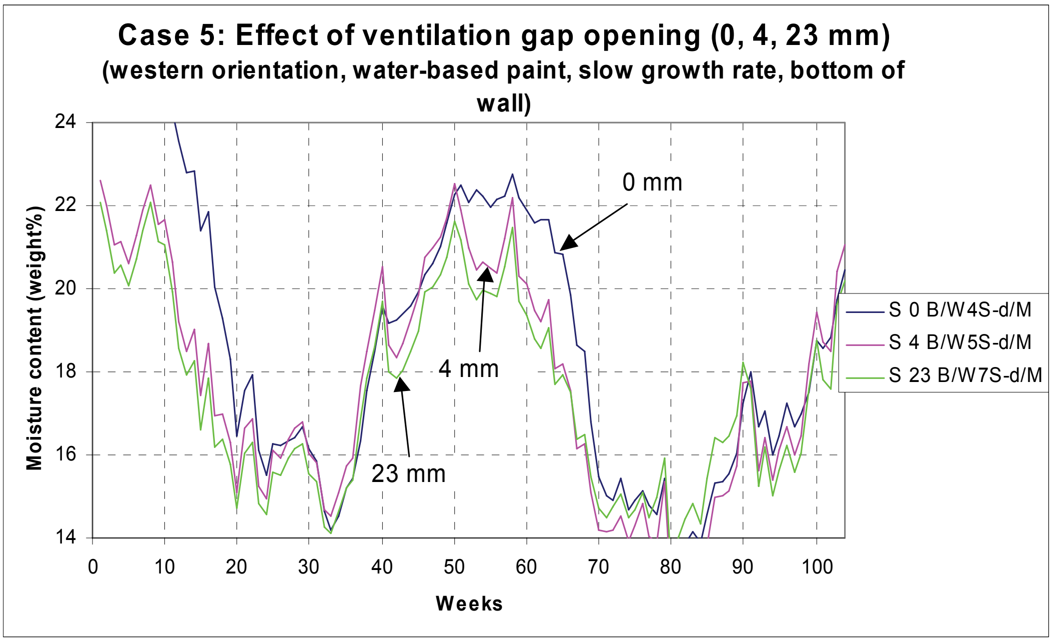

Figure 5.4

The findings above is confirmed when we control the calculated mould growth potential "Maxdays" in Table 4.4. For western orientation we find a mould growth potential for 0 mm air gap opening that is approximately twice as large as for 23 mm opening. When comparing the mould growth potential for 4 and 23 mm air gap openings we find no clear difference, but there are indications of lower mould growth potential for the 23 mm air gap opening.

5.4 Variation of MC with height of wall

MC are measured in both the top and bottom part of the wall, see Figure 3.2. The variation of MC and mould growth potential with height of wall can be observed in Figure 5.5, cases 9 – 12g in Appendix 4 and in Tables 4.2, 4.3 and 4.5. As Table 4.5 shows that the difference between the top and bottom part of the wall can be significant. However in some cladding configurations the highest MC and mould growth potential occurs in the bottom part of the cladding, while in other the highest MC occurs in the top of the cladding. There is however a clear tendency for higher MC and mould growth potential in the top of the wall for the elements with western orientation (high driving rain exposure) and no air gap opening (see cases 9, 12b, 12d in Appendix 4 and Figure 5.5). An explanation could be that even though the openings are attempted closed there will be some small unintended openings. This will give a small air velocity upwards. The humidity of the air will increase as the air moves upwards in the air gap (uptake of moisture drying from the cladding), and the drying capacity from the cladding to the air gap will decrease.

Another trend that can be observed in Table 4.5 is that for eastern orientation and 4/23 mm air gap opening there is a clear tendency for higher mould growth potential in the bottom of the wall. One explanation could be a higher degree of surface condensation at the bottom part of the wall due to the roof eaves, e.g. see Nore, Thue and Rydock (2006). Another explanation could be that the outdoor air entering the air gap in the bottom has a higher RH than the air in the top of the air gap. The temperature of the air will increase with height, causing the RH to decrease if there is negligible moisture coming from the cladding.

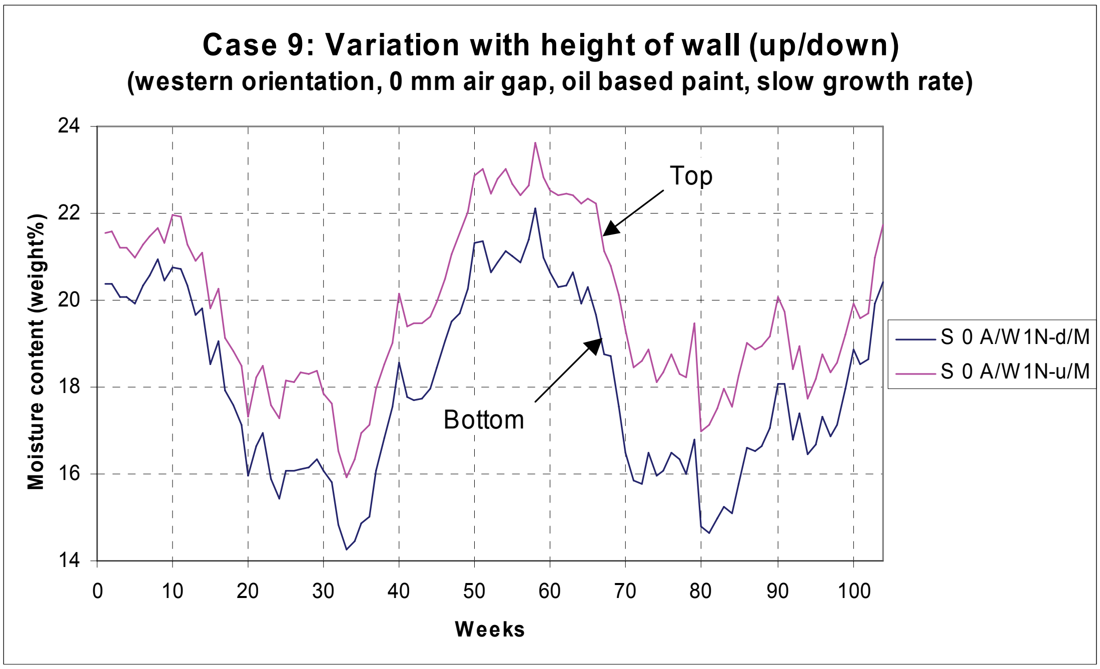

Figure 5.5

5.5 Effect of surface treatment

The effects of surface treatment on MC are shown in case 13-16 in Appendix 4 and Figure 5.6. We see that there are in general relative little difference between oil based and water based paint in regard to the effect on MC.

For the western orientation (high driving rain exposure) with no air gap opening (see Figure 5.6) we do however observe a higher MC for the oil based paint compared with water based paint. This is probably due to the fact that with no air gap most of the moisture in the wall and the cladding has to dry out by vapour diffusion through the cladding. Since the oil based paint has a higher vapour resistance than the water based the drying process after wetting will be slower. A similar effect can be seen for the eastern orientation with 4 mm air gap opening (see case 16). It is however more difficult to explain this effect since there are little driving rain and there are a certain ventilation of this cladding.

When comparing untreated and treated claddings we do however see large differences. Untreated claddings generally have both the highest and lowest MC. See Figure 5.7. Untreated claddings also show a much higher degree of fluctuating MC, i.e. the water uptake and drying processes beeing much faster than for treated claddings (see case 15 and 16). These effects are most pronounced for the western orientation (high driving rain exposure). This is of course as expected, since a treatment will slow down both the water uptake and the drying.

The findings above is partly confirmed when we control the calculated mould growth potential "Maxdays" in Table 4.6. There is a tendency for higher mould growth potential for claddings with water dispersed paint compared to oil based paint when eastern orientation . For the western orientation there may be a tendency for slightly higher mould growth potential for the oil based paint when there is no air gap, and the opposite when there is 4/23 mm air gap. We find a generally higher (approx. twice as high) mould growth potential for the untreated cladding compared to claddings with oil based paint.

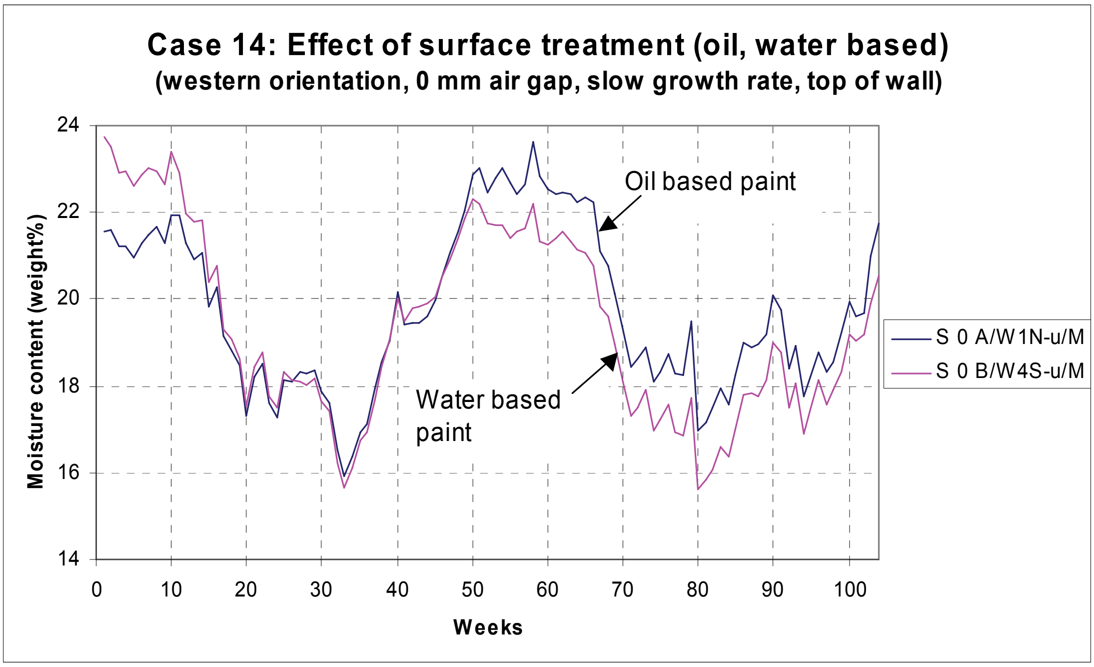

Figure 5.6

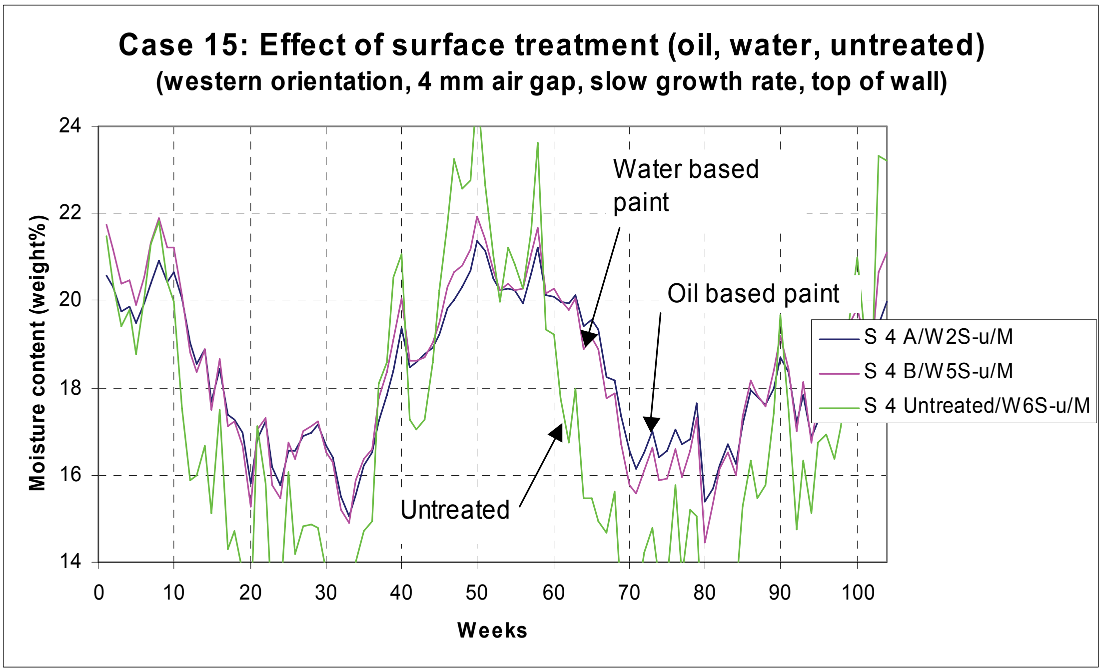

Figure 5.7

5.6 Effect of driving rain exposure (orientation)

The effect of driving rain exposure is also discussed in Chapter 5.3 and 5.8.

We observe that the driving rain exposure (eastern or western orientation) is the factor affecting the MC the most (see case 17 – 19). We find the largest difference for the case with no air gap, showing a difference in MC between western and eastern orientation of up to 4 weight% during winter period (see cases 18 and 19). See Figure 5.8. On the other hand we find that with a ventilated air gap the difference is much smaller, i.e. 1-2 weight%, see

Figure 5.9 and 5.10. We see this effect regardless of type of paint and for unpainted claddings. This show the importance of ventilating the air to secure low moisture content to walls exposed to driving rain.

The fact that we find the largest differences for the cases with no air gap is relatively easy to explain. See discussion in chapter 5.3.

The findings above is confirmed when we control the calculated mould growth potential "Maxdays" in Table 4.7.

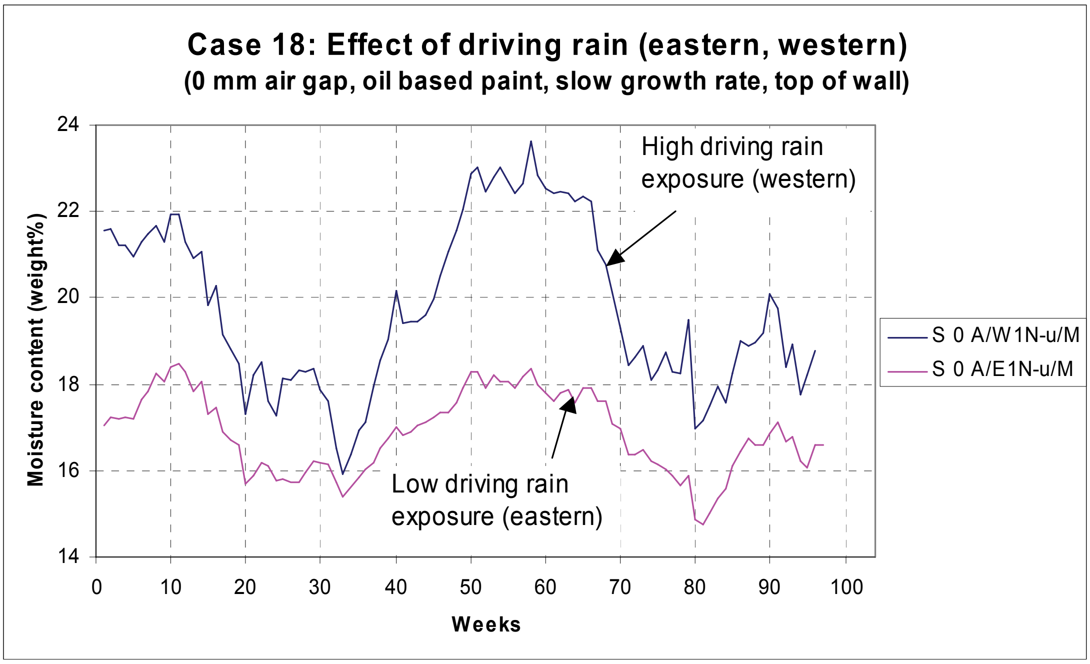

Figure 5.8

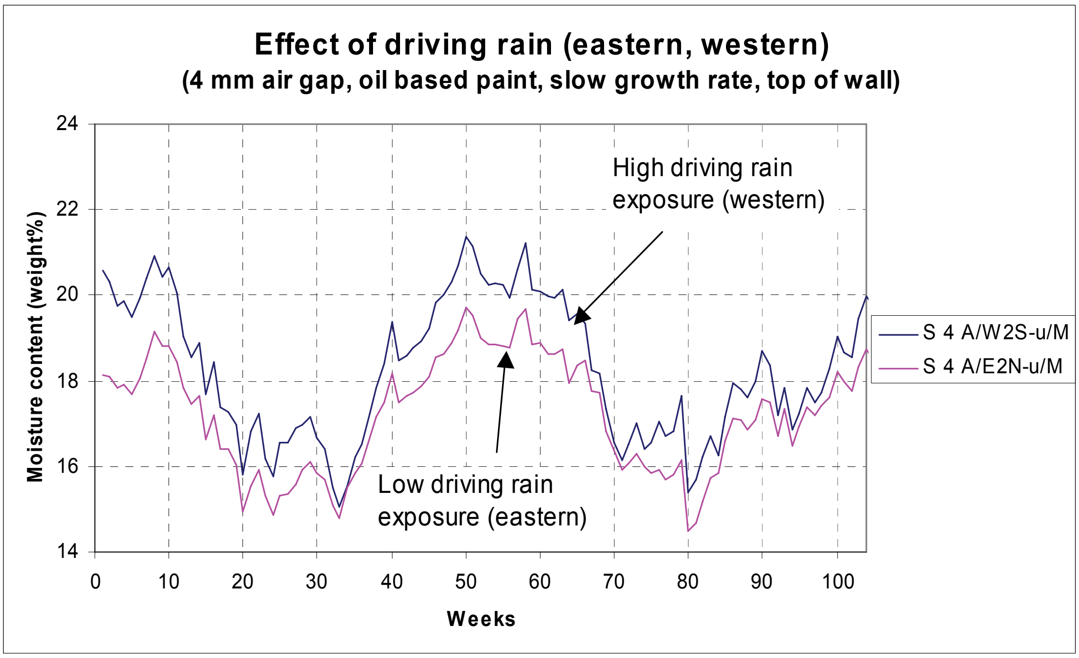

Figure 5.9

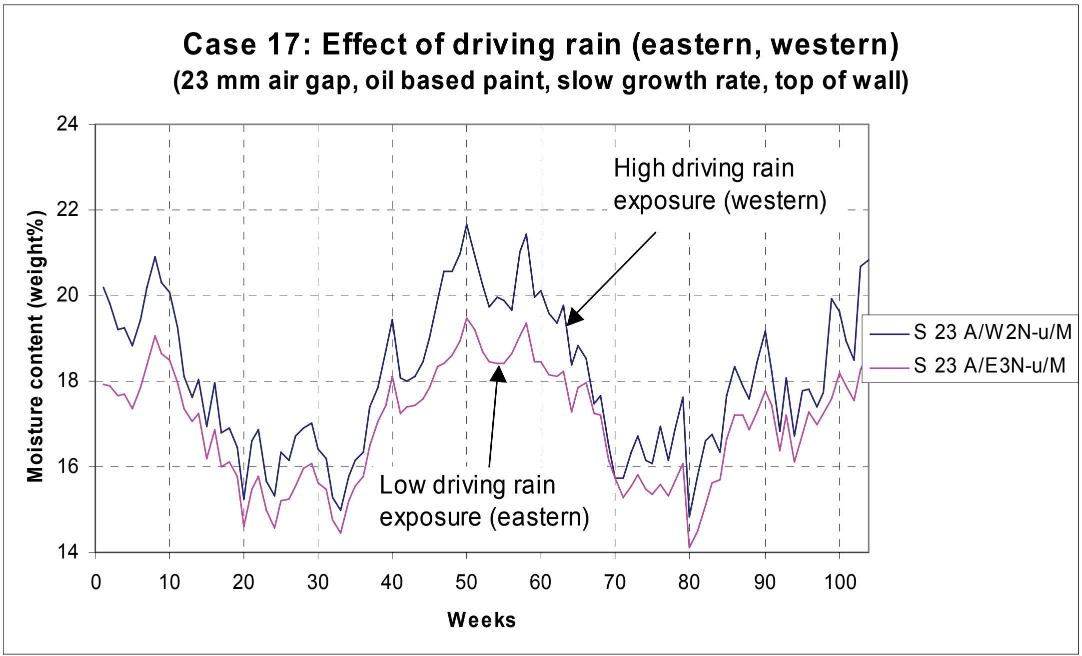

Figure 5.10

5.7 Effect of growth rate of wood

The effects of growth rate are illustrated in case 21-25 in Appendix 4. We see that there are in general relative little difference between slow grown and fast grown spruce in regard to the effect on MC.

When looking at the calculated mould growth potential "Maxdays" in Table 4.8, comparing fast grown and slow grown wood we do see some differences. There is however no clear trend of one type of wood having a higher risk for mould growth. It is interesting to see that the difference in "Maxdays" is rather small for the western orientation. We also see that there is no difference for the untreated cladding, where we might have expected the largest difference (according to a hypothesis that slow grown wood has a slower moisture uptake of rain water). Though it can be argued whether the densities 385 kg/m^3 and 460 kg/m^3 really represents fast grown and slow grown wood.

5.8 Short term moisture uptake and drying after a driving rain spell

The hourly values of MC shows of course higher variations and fluctuations than the weekly averages of MC. In Figure 5.11 the hourly variation is shown for three different panels. We see however that the moisture response is not very quick in terms of hours. The moisture response from one hour to another is seldom more than 0,1-0,3 weight%.

If we consider the driving rain spell during the period Hour 6350-6375 (1 day) we see an increase in MC of approx. 3 weight% for the untreated panels with western orientation and approximately 1 weight% for the painted panels with western orientation. For the painted panels with eastern orientation (with no driving rain) the moisture response is significantly lower (approx. 0,3 weight%).

For comparison the driving rain and RH of the air is given for the same period in Figures 5.12 and 5.13. It can bee seen that the RH increases up to 90% during the period of rain. The

MC during rainy periods are probably dominated by moisture uptake of rain, but there are also some effect from the general increase of RH in the air.

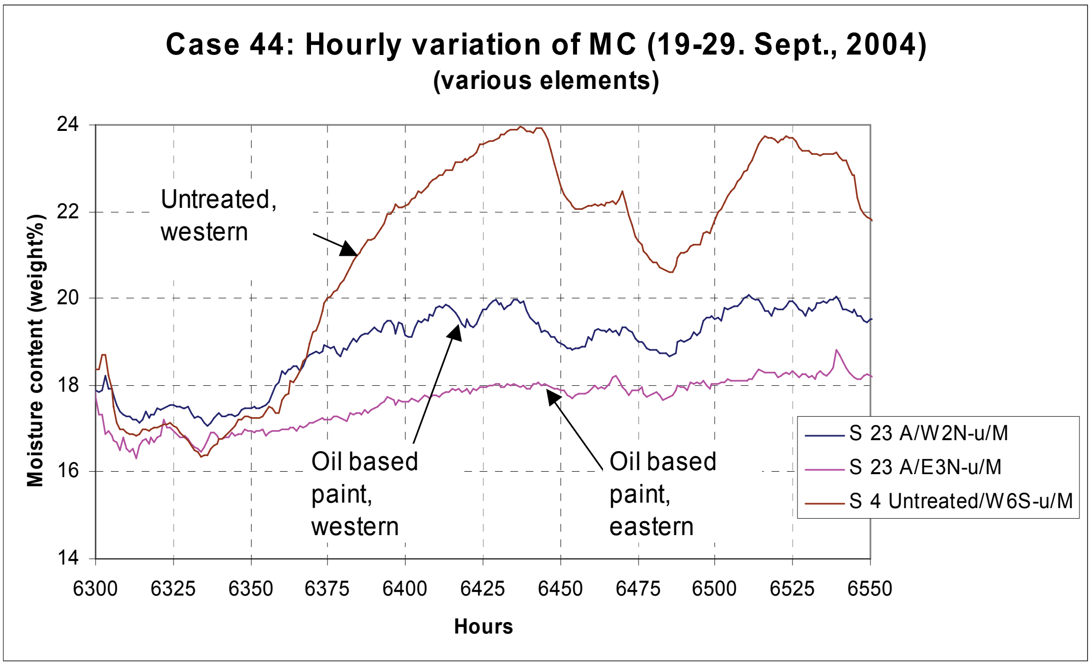

Figure 5.11
Hourly values of MC for 10 days in September 2004 for three different wall sections.

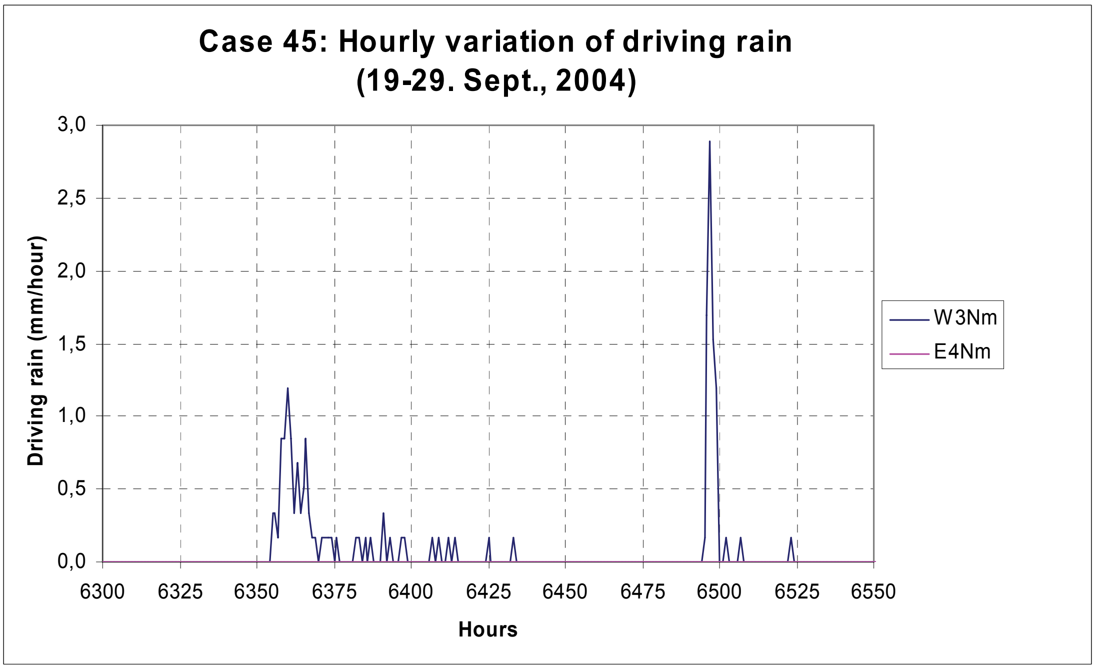

Figure 5.12
Hourly values of driving rain for 10 days in september 2004.

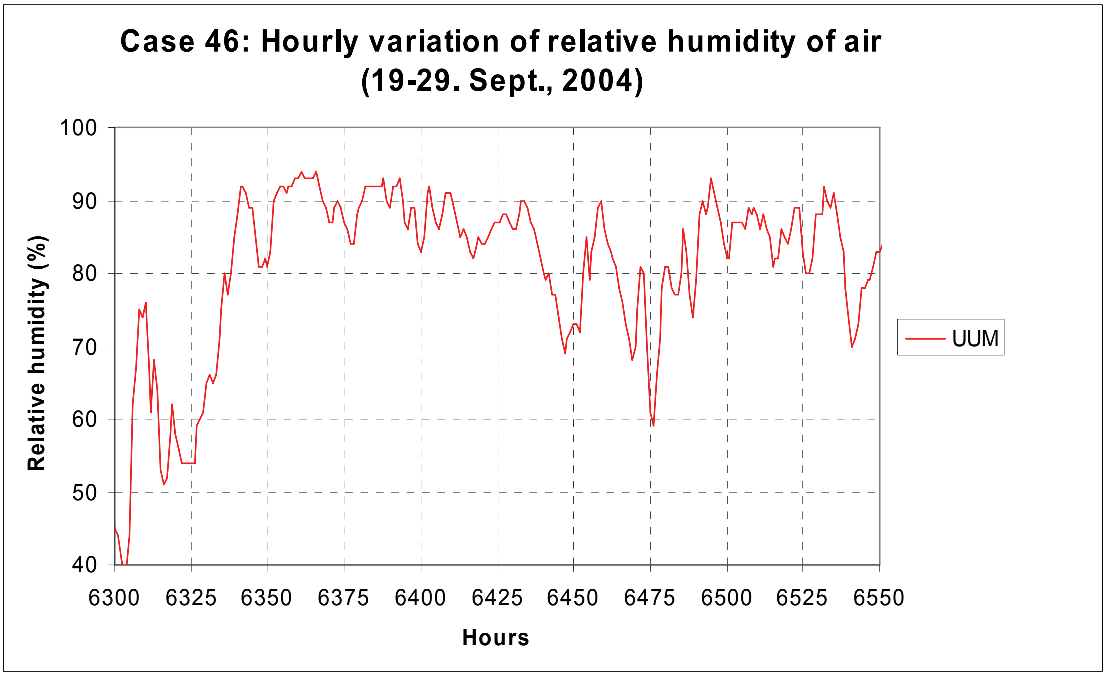

Figure 5.13
Hourly values of relative humidity for 10 days in september 2004.

5.9 Temperature in cladding

The temperature of the cladding and the air cavity behind may be of some importance on the moisture conditions of the cladding. Especially for the ventilated claddings the temperature may be difficult to model. Some graphical outputs of the temperature measurements are therefore presented in Appendix 4 (Case 26-30). These measurement results are however not discussed any further in this report – except for the following analysis.

To show some of the effect of the degree of ventilation on the temperature condition a comparision of the temperature in the bottom part of the cladding have been made for the three-months period December - February, see Table 5.1. Except for one element (fast grown, oil based, 23 mm) there is a clear trend of a lower temperature in the cladding the the larger the air gap opening. The difference is however not large (0,3-0,4 °C difference between 0 and 23 mm air gap opening). Because of the general measurement uncertainty of the method it is difficult to make any conclusions.

Table 5.1
Average temperature in bottom part of cladding during the period December 2004 – February 2005 (only eastern elements). The average air temperature measured outside of section E4-S (see #13 in Table 3.3 and Figure 3.6) was 0,1 °C for the same period.

	Average temperature in cladding			
Air gap opening (mm)	**Slow grown / oil based (°C)**	**Fast grown /oil based (°C)**	**Fast grown /water based (°C)**	**Slow grown /water based (°C)**
0	1.0	0,8	0,6	0,5
4	0,8	0,5	0,4	0,3
23	0,6	0,8	0,2	0,2

5.10 Variation of MC with depth in the cladding

The standard MC-sensors were uninsulated pins intruding from the back of the cladding till 3 mm from the external surface. For four wall sections some extra pins were installed measuring the MC at specific depths in the cladding, see Figure 3.4 and Table 3.3. Some of these measurements are shown in Appendix 4 (Case 31-36).

Generally we find that there is a moisture profile over the cladding, with the highest MC in the outer part and lowest in the inner part, see example in Figure 5.14 The difference in MC seems generally to be larger between inner/middle part than between outer/middle part for wall sections with 23 mm air gap, but the opposite for the one with only 4 mm air gap opening.

Generally the uninsulated standard pins show a higher MC than any of the insulated pins. This is logical since the total electrical conductivity beween the uninsulated pins is a sum of the conductivity over the thickness of the cladding. This means that even if the uninsulated pin and the insulated pin in the outer part are intruded to the same depth (and the highest MC is in the outer part), the uninsulated pins will measure a higher MC.

In Case 32 (see Appendix 4) we can see that the insulated pin in the outer part measures higher MC during certain periods. This is probably caused by the insulated pin being intruded closer to outer surface than intended or due to the anisotropic structure of the wood. This indicate that the uninsulated pins give a better picture of the MC-level in the outer part compared with the insulated pins.

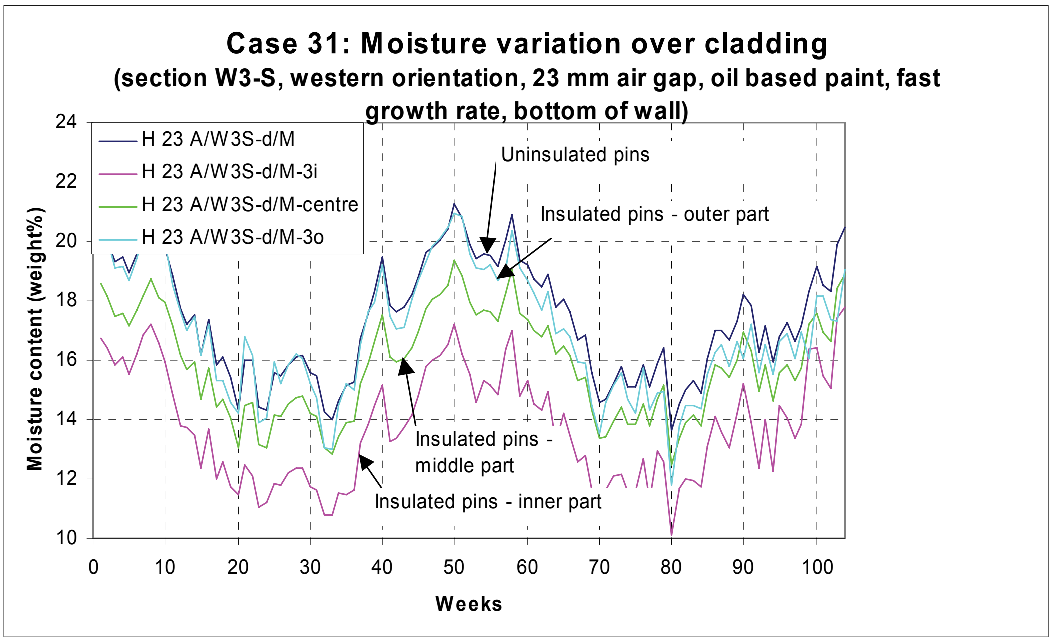

Figure 5.14

5.11 RH in air gap

Measurements of RH have been performed on five elements, the results are shown in Case in Figure 5.15 and 5.16. For western orientation it can be seen that the smaller the ventilation gap opening, the higher RH. The difference is highest dyring late winter and spring. This coincides relatively well with the measured MC of the cladding, e.g see Figure 5.4.

In Figure 5.16 the outdoor RH is shown together with the RH in the air gaps of two eastern oriented sections. We see that for 23 mm air gap opening the RH follows the fluctuations of the outdoor air relatively close. With no air gap opening the RH of the air gap have more damped fluctuations. This is as expected; with an air gap opening the RH of the air gap will depend more heavily on the outdoor air than for the case with no air gap opening.

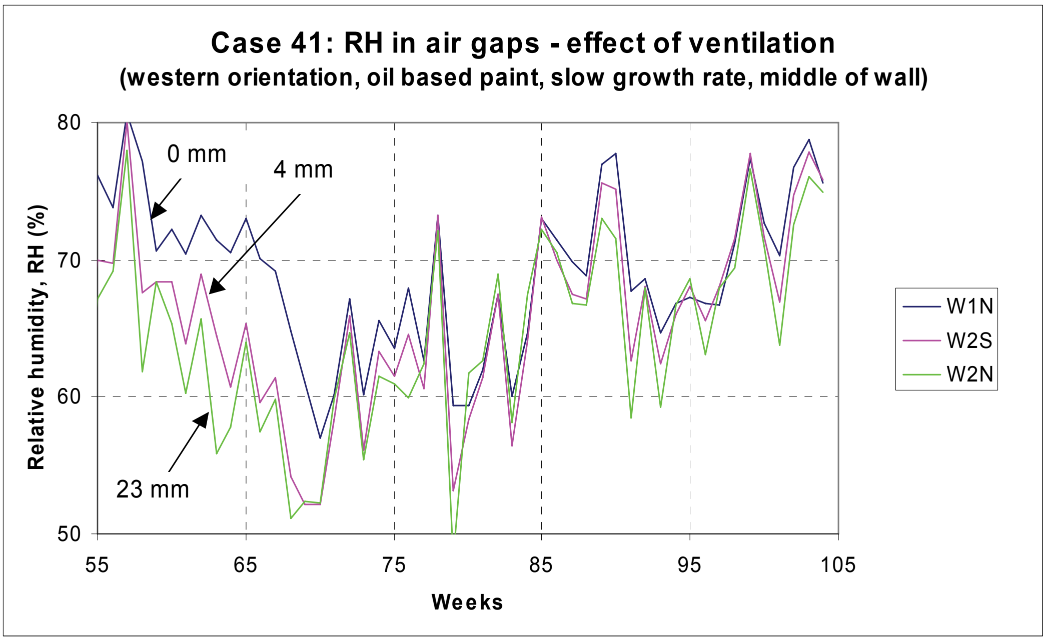

Figure 5.15

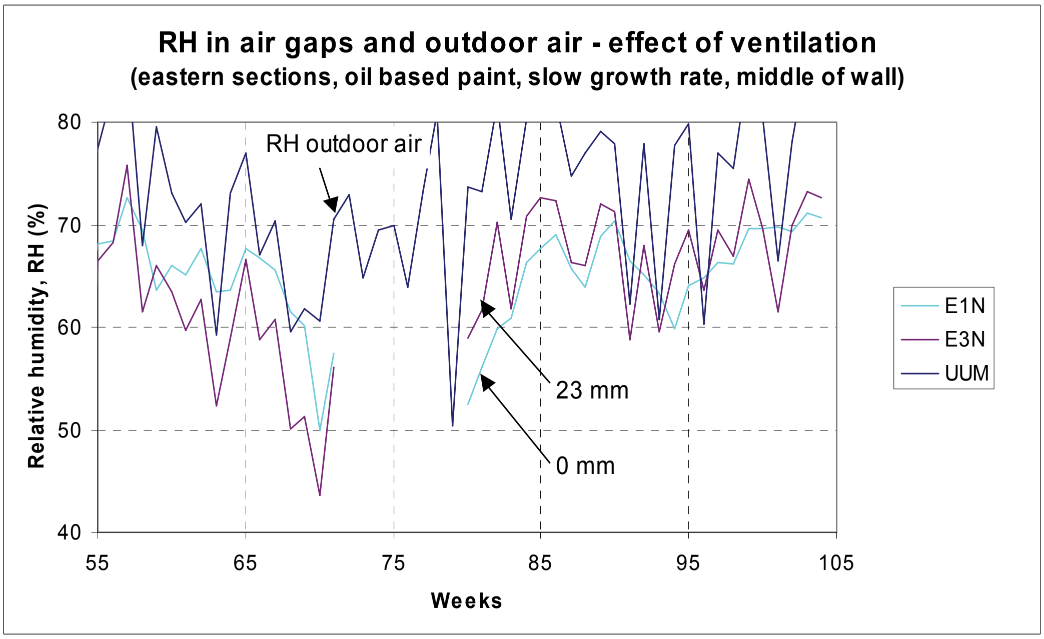

Figure 5.16

5.12 Effect of removing support battens (no air cavity behind panel)

For two elements (W5N and E5S) the vertical battens were removed and the cladding mounted directly onto the windbarrier in May 2005 (i.e. from 23 mm to 0 mm air cavity). The results for these two elements are shown in Figure 5.17 and 5.18 for the last half of 2005 (week 80 – 105), comparing with some other elements. Even though the shown measurement period is rather limited (only a half year) we see some interesting results. For the period shown in the figures we see no dramatic difference between the elements with and without an air cavity in how the moisture content increases during the autumn.

For the drying season during spring one might however expect that the elements without air cavity behind the panels will experience a slower drying process. It must also be noted that the tested type of wooden panel is relatively water tight, i.e. there will probably be only limited amounts of rain water penetrating to the backside of the panel. A less water tight type of cladding will be more at risk in regard of high moisture content, mould growth and moisture damages for the interior part of the wall.

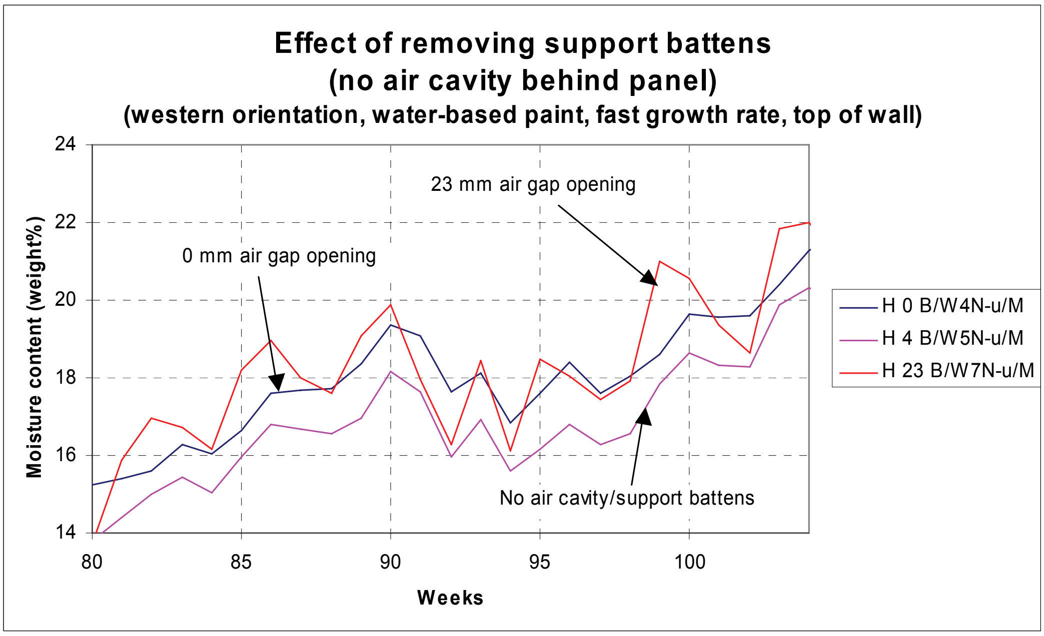

Figure 5.17

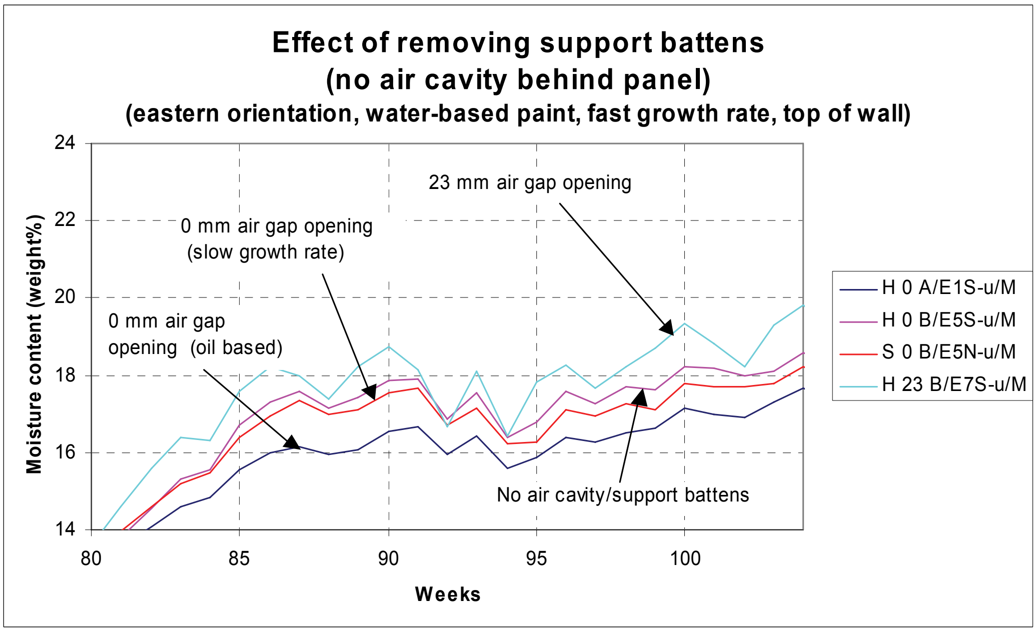

Figure 5.18

5.13 Driving rain measurements

When comparing free field measurements of driving rain with the amount actually hitting the wall we find that there is considerable less hitting the wall compared to the free field measurements. See Case 37-40 (Appendix 4) and Figure 4.6 and 4.7. For the western orientation the free field accumulated value is 1060 mm for the two year period 2004-2005. For comparison the average of the four gauges on element W3-N is 208 mm for the same period, i.e. only 20% of the total free field value.

A more thorough analysis of the driving rain data are given in Nore, Blocken, Jelle, Thue and Carmeliet (2006).

5.14 Publications where data from this project have been used

Lauter, P. and Time, B. (2005):
This paper analyses the measurements at Voll for 2004. The importance of the various factors such as local location, surface treatment, material quality and micro location are analysed.

Nore, K., Thue, J.V., Time, B. and Rognvik, E. (2005):
In this paper the measurement set up for 14 timber cladding sections are presented. A few preliminary results are presented, they respond to earlier findings on wooden cladding design.

Nore, K., Blocken, B., Jelle, B.P., Thue, J.V. & Carmeliet, J. (2006):
In this paper the measurement set up for wind driven rain investigation at Voll is described. The data logged is posted on a website and made available to other researchers on free field wind driven rain. .

Nore, K., Thue, J.V. and Rydock, J.P. (2006):
In this paper the measurements of liquid water on the wall is presented. The time-of-wetness sensor on the wall surface has a good correlation to the registered wind driven rain, condensation and assumed drying out period and thus gives valuable information in further surface moisture analysis.

Nore, K., Lisø, K.R. and Thue, J.V. (2006):
This paper analyses the measurements at Voll for 2004. Correlations coefficients are found for the correlation of meteorological data gathered at the nearby meteorological station and the corresponding moisture values of the wooden claddings. The wind speed is shown to have a grater effect than described in earlier publications.

Nore, K., Zillig, W. & Thue, J.V. (2006):
In this paper the moisture content is calculated by the numerical tool WUFI and validated to the Voll measurements. Then the numerical model is used to calculate the wooden cladding behaviour at other climates, in Oslo, Bergen and Tromsø. The paper gives promising results in order to efficiently use model tools to run future research on climate adapted building in Norway.

6 Conclusions

6.1 Ventilation gap opening

The results show clearly that:

- Air gap openings in the top and bottom part of the cladding limits the moisture content in wooden claddings exposed to driving rain.
- An air gap opening in the top and bottom part of the cladding equivalent to a 4 mm continous air gap is sufficient to limit the moisture content of wooden claddings exposed to driving rain.
- For climates, orientations or geometries where only small amounts of driving rain hits the wall the wooden cladding might even perform better with no planned air gap openings at all.

It is possible that the total area of the air gap opening in the top and bottom part of the cladding can be even smaller than a 4 mm continous air gap, if there are sufficient drainage openings in the bottom part of the wall. In Norway it is usual to define that drainage openings in the bottom part of the wall should be minimum 5 mm wide (see Kvande et. al., 2003), to give free drainage. The drainage openings (that also function as ventilation openings) do however not need to be continous.

Regarding wooden claddings that are exposed to only small amounts of driving rain it will be an unnecessary risk not to ventilate the cladding, even if the results show low moisture content with no air gap opening. With a more air tight cladding, a more vapour tight surface treatment or with air leakages or vapour diffusion from a moist indoor air environment, the results may would have been different than shown in this study.

The practical reccomendation for wooden claddings based on previous experience and the results of this study are then as follows:

- Wooden claddings should be ventilated in the top and bottom part, regardless of degree of exposure to driving rain.
- Openings in top and bottom part of the wall equivalent to a 4 mm continous air gap is sufficient. The openings do however not need to be continous, see for instance a traditional Norwegian vertical board and board cladding where there are openings only behind the top board.
- There must be a drainage system consisting of :
  - An air cavity behind the panel wide enough and with a system of e.g. support battens/counter battens that ensure that water penetrating the panels do not reach the wind barrier in amounts that may damage the inner part of the wall.
  - Drainage opening(s) in the bottom part of the wall minimum 5 mm wide.

6.2 Surface treatment

The results show relative little difference between oil based and water based paint in regard to the risk for decay and microbiological growth. For cases with both high driving rain exposure and no air gap opening, we find a slightly higher risk for decay with the oil based paint. On the other hand, for cases with both high driving rain exposure and 4/23 mm air gap opening, we find a slightly lower risk for decay with the oil based paint. These differences are so small that we cannot conclude any of the paints being better than the other.

Regarding untreated claddings we find that the risk for decay and microbiological growth is generally higher for these cladding types compared to painted claddings. It may however be said that even if the risk is higher with untreated claddings, the results do not indicate that the risk is critically higher.

6.3 Growth rate of wood

The results show little difference between slow grown and fast grown spruce in regard to the risk for decay and microbiological growth. For the interval of wood densities investigated in this study (385 kg/m^3 called fast grown versus 460 kg/m^3 called slow grown) we cannot conclude that slow grown wood is significantly better than fast grown.

7 Literature

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Appendix 1

AUTOMATIC WEATHER STATION

Standard measurements

Outdoor climatic data are measured by a Milos 500 Vaisala automatic weather station (AWS) located 17 m to the south of the test house. Hourly values of air temperature, relative humidity, air pressure, wind speed, wind direction, precipitation, global radiation and longwave radiation are recorded. The sensors used in the Milos 500 Vaisala AWS are shown in Table A1.1.

Table A1.1
Sensors used in the Milos 500 Vaisala AWS

Type	Trade name
Air temperature and humidity sensor	Vaisala HMP 35D
Pressure sensor	Vaisala DPA 21
Wind speed sensor	Vaisala WAA 15A
Wind direction sensor	Vaisala WAV 15A
Precipitation amount	Geonor
Precipitation detector	Vaisala DRD 11A
Solar radiation pyranometer	Kipp & Zonen CM 6B
Pyrgeometer	Kipp & Zonen CG 1

The AWS has been operating since 15. March 1995. From 1. March 1996 the Norwegian Meteorological Institute took over the operation of the AWS, ensuring a good quality of the measurements. Since then there is only missing data for a few and short periods. Before 1. March 1996 there were several periods when the AWS was not working. The most serious breakdown took place in the period 15. October 1995 - 29. February 1996 because of serious vandalism on the weather station.

In Table A1.2 are shown the format of the meteorological parameters measured and recorded since 1. March 1996. These data can be read by a spreadsheet, with the parameters number 1 - 29 in a row, one row for every hour.

The AWS measures most parameters every five seconds (wind every second). Averages over 60 seconds are calculated (minute values), and these are used to find the hourly values described in Table A1.2. The hourly values are generated at every shift of hour and consist of:

- Instantaneous value = minute average last minute before shift of hour
- Maximum value = maximum minute average last hour
- Minimum value = minimum minute average last hour
- Average value = average of all minute values last hour

Regarding longwave radiation it should be noted that it is the longwave downward radiation to the instrument (L_{down}) that is measured (QL and QLX in Table 2), and not the net longwave radiation (L_{net}). L_{down} is calculated with the following formulae:

$$L_{down} = \frac{V}{K} + 5.67 \cdot 10^{-8} \cdot T_s^4$$

where V is output of the pyrgeometer (V), K is a calibration factor (Vm^2/W) and T_s is the sensor temperature (K). If net longwave radiation (L_{net}) is wanted the longwave radiation part of the formula above should be subtracted for the specific medium. For example for the sensor L_{net} is calculated as follows:

$$L_{net} = L_{down} - 5.67 \cdot 10^{-8} \cdot T_s^4$$

In addition to global radiation, most heat-, air- and moisture programs also require values for diffuse- and direct solar radiation. A program ("vollfil") was developed that estimated the hourly values of diffuse and direct solar radiation from global radiation. The program reads a climatic file and is then able to generate climatic files including diffuse- and direct solar radiation on different formats.

Table A1.2
Format of the meteorological parameters measured and recorded since 1. March 1996

No.	Symbol	Parameter	Unit
1	TT	Temperature, last minute last hour	°C
2	TTM	Temperature, average last hour	°C
3	TTN	Temperature, minimum last hour	°C
4	TTX	Temperature, maximum last hour	°C
5	UU	Relative humidity, last minute last hour	%
6	UUM	Relative humidity, average last hour	%
7	FF	Wind speed, last 10 minute average last hour	m/s
8	FM	Wind speed, average last hour	m/s
9	FG	Wind speed, 3 seconds max. gust last hour	m/s
10	FX	Wind speed, max. 10 minute running average last hour	m/s
11	DD	Wind direction, belongs to FF (0° = north, 90° = east, etc)	°
12	DM	Wind direction, belongs to FM	°
13	DX	Wind direction, belongs to FX	°
14	RA	Total content in rain gauge	mm
15	RR	Increase in rain gauge last hour	mm
16	RT	Number of minutes precipitation last hour	0 - 60
17	PO	Air pressure in height of station, last minute last hour	hPa
18	POM	Air pressure in height of station, average last hour	hPa
19	PON	Air pressure in height of station, minimum last hour	hPa
20	POX	Air pressure in height of station, maximum last hour	hPa
21	PP	Air pressure, reduced to sea level, standard formulae	hPa
22	PF	Air pressure, reduced to sea level regarding temperature	hPa
23	PT	Air pressure difference, 3 hours	hPa
24	AA	Air pressure characteristics, 3 hours (SYNOP-code)	0 - 8
25	QO	Global radiation, accumulated last hour	W/m^2
26	QOX	Global radiation, maximum last hour	W/m^2
27	QL	Longwave radiation, accumulated last hour	W/m^2
28	QLX	Longwave radiation, maximum last hour	W/m^2
29	SS	Snow depth, last minute last hour	cm

Appendix 2

TEST HOUSE CONFIGURATIONS

Logging system

The logging system is a combined system of loggers and communication software on PC. Three loggers (Campbell CR 10) are each connected with the measurement sensors trough a multiplexer (Campbell AM 32 B). For the temperature measurements a common reference was used for each multiplexer. The loggers each have an internal temperature reference, but they were also connected with an external temperature reference (Campbell 10TCRT Thermocouple Reference).

Because of very high electrical resistance (low levels of electrical current) coaxial cables were used for the moisture measurements to avoid that electrical noise from other electrical cables and equipment influenced the measurement signals. To convert the measurement signals (voltage) to moisture content a converter (Delmhorst MT(G) 40) was inserted between the loggers and the multiplexers. This conversion is further described in chapter 3.3.3.

Heating and ventilation

The test house is equipped with a low temperature electric floor heating system, i.e. a Flexel Mark III heating foil with maximum power output of 90 W/m^2. The heating foil is automatically regulated through a thermostat with a temperature sensor in the room air. Throughout the measurement period the temperature of the room was maintained at approximately 23 °C.

Appendix 3

METHOD FOR CALCULATING MOULD GROWTH POTENTIAL

The growth rate of moulds and other fungi (such as brown rot) are strongly dependant of the temperature and moisture conditions of the materials. Based on finnish studies of growth rate of moulds on wooden surfaces (Viitanen and Ritchkoff, 1991; Viitanen, 1994) a quantified relation between growth rate and relative humidity and temperature on the material surface have been made (Geving, 1997). Based on these relations some simplifications have been done for easier calculation (Uvsløkk, 2005).

The relations used are given in Figures A3.2, A3.3 and A3.4. The diagrams shows relative mould growth rate wich is the relation between growth rate at the actual RH and/or temperature and the maximum growth rate. Relative growth rate is therefore a number between 0 and 1. Figure A3.4 is made by combining the two first diagrams, and multiplying the growth rates depending on RH and temperature.

Based on weekly averages of temperature and moisture content in the wooden claddings the mould growt potential called "Max-days" are calculated for a one year period. First the moisture content are transferred to RH using a sorption isotherm for spruce, see Figure A3.1. Then the relative growth rate is calculated for each week (multiplied with 7 to get the notation "days") and the sum for the whole year is calculated. The potential is then given as an equivalent number of "Max-days". That equals the number of days with maximum conditions for growth giving the same amount of growth as for the actual RH and temperature conditions. For example will one week with an RH and temperature giving 10% of maximum growth rate, give a potential equal to 0,7 days with maximum growth (0,1 x 7). The potential for each week is summed for the year to give the number of "Max-days" for a whole year.

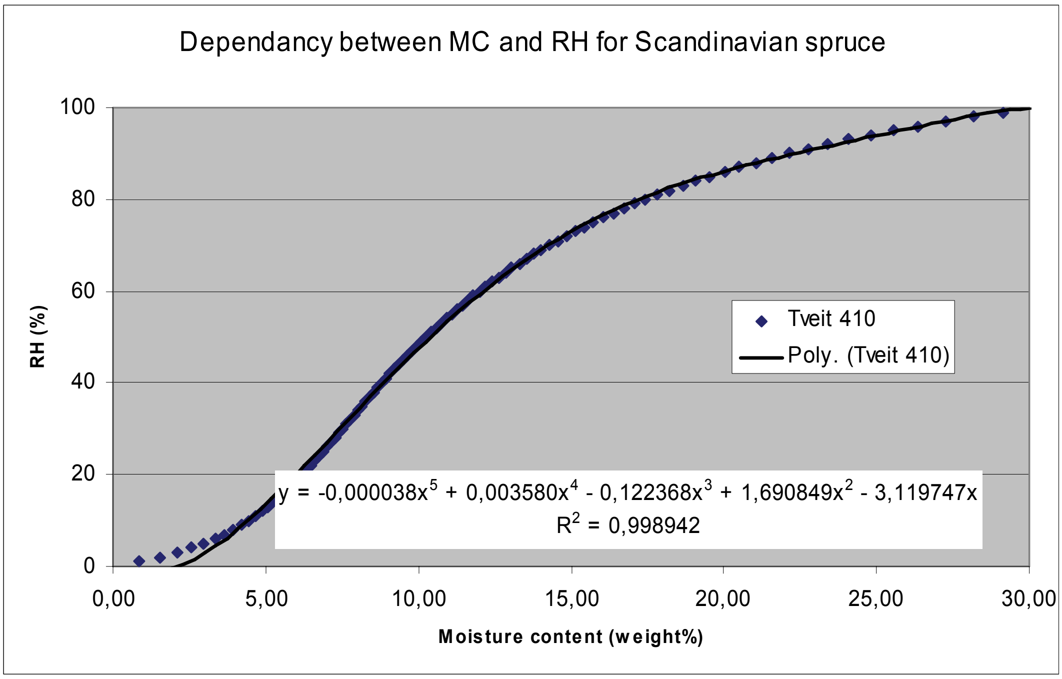


Figure A3.1
Sorption isotherm used to transfer the measured moisture content of the cladding to the equivalent RH. Data is based on measurements of Tveit (1966) on Scandinavian spruce with a density of 410 kg/m^3.

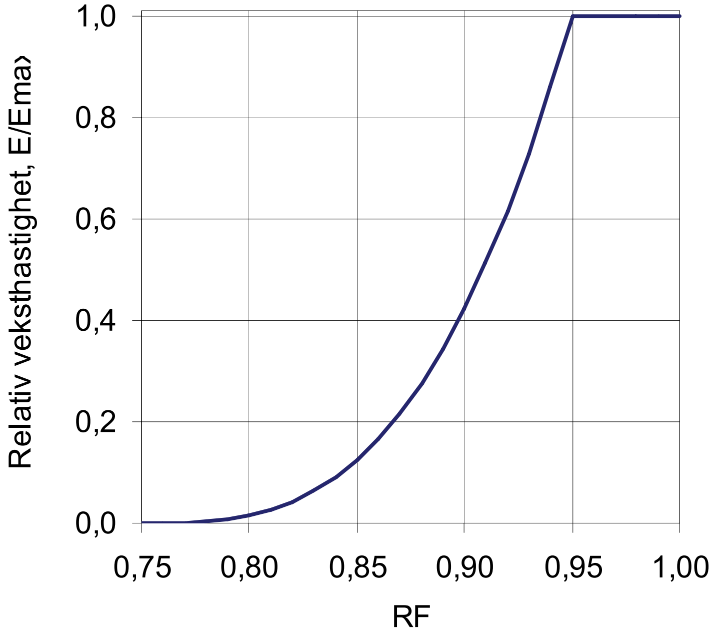


Figure A3.2
Relative mould growth rate depending of relative humidity, φ.
At φ < 0,75 (RF < 75%) it is assumed there is no growth. At 0,75 < φ < 0,95 the relative growth rate is calculated with the expression $E/E_{max} = ((\varphi - 0,75)/2)^3$. When relative humidity is above 0,95 the growt rate is considered at maximum for the given temperature.

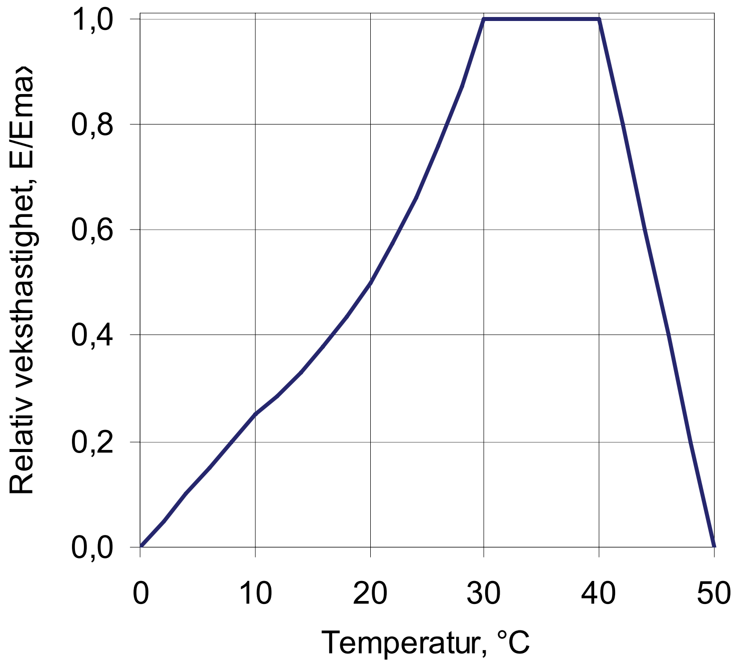


Figure A3.3
Relative mould growth rate depending of temperature. When the temperature is lower than 0 °C or higher than 50 °C it is assumed to be no growth. In the temperature interval +10 - +30 it is assumed that the growth rate is doubled per 10 °C increase in temperature. In the other intervals it is assumed that the growth rate varies linearly with temperature as given in the figure.

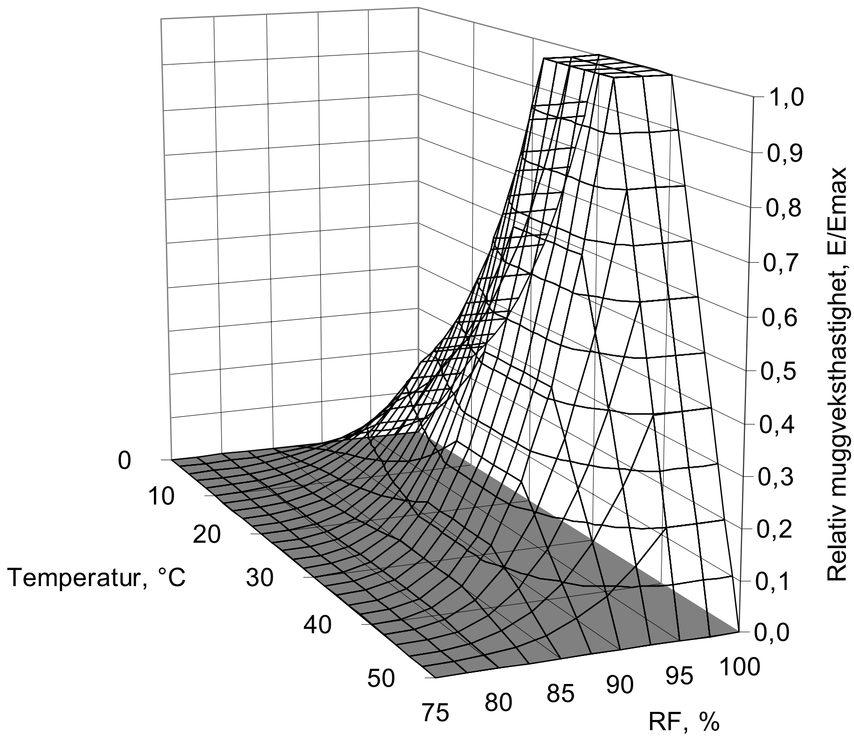


Figure A3.4
Relative growth rate dependant of both RH and temperature. The digram is made by combining (multiplying) the diagrams in Figure A3.2 and A3.3.

Appendix 4

GRAPHICAL RESULTS

The main graphical output weekly averages of measured values are given in this Appendix. The codes used to identify the measurement points are described in Table A4.1. The various Cases are described in Table A4.2.

Example of code:
S 23 A/E3N-d/M
= slow grown, 23 mm air gap opening, oil based paint, test section E3N, measurement point in bottom part of wall, moisture content in cladding (uninsulated pins)

Id. no	1	2	3	4	5	6
Example	S	23	A	E3N	d	M

Table A4.1
Identification codes<

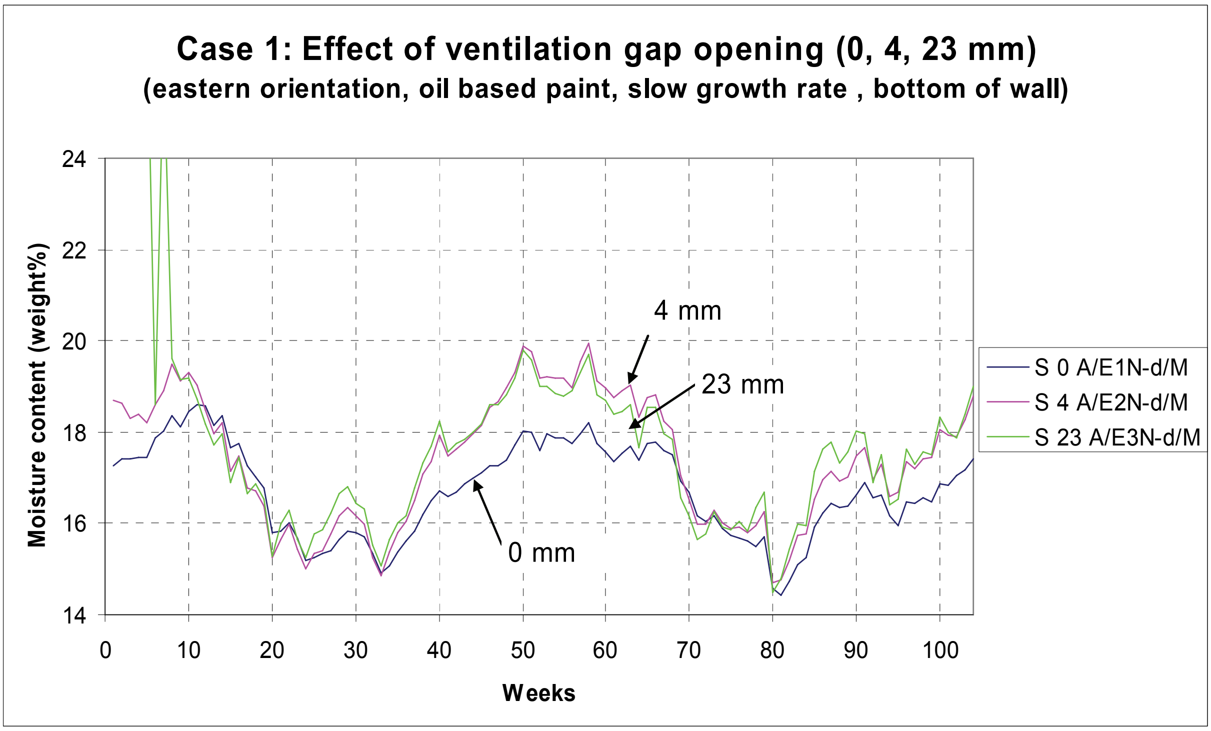
Id. no	Group	Types
1	Growth rate wood	S = slow grown H = fast grown
2	Air gap opening	0, 4 or 23 mm
3	Surface treatment	A = oil based paint B = water dispersed paint Untreated = no surface treatment
4	Test section	Section idientifier
5	Measurement height	d = bottom part of wall u = top part of wall m = middle part of wall
6	Type of measurement	M = MC in cladding (uninsulated pins) M-3o = MC in cladding – 3 mm from outer surface (insulated pins) M-centre = MC in cladding – middle of cladding (insulated pins) M-3i = MC in cladding – 3 mm from inner surface (insulated pins) T = temperature in middle of cladding T-cladding = Temperature on cladding surface – inside T-wind barrier = Temperature on wind barrier surface (alt. T-wb) T-air gap = Temperature in air gap (alt. T-cavity) T-cs = Temperature on cladding surface – outside T-air = Temperature of air outside section

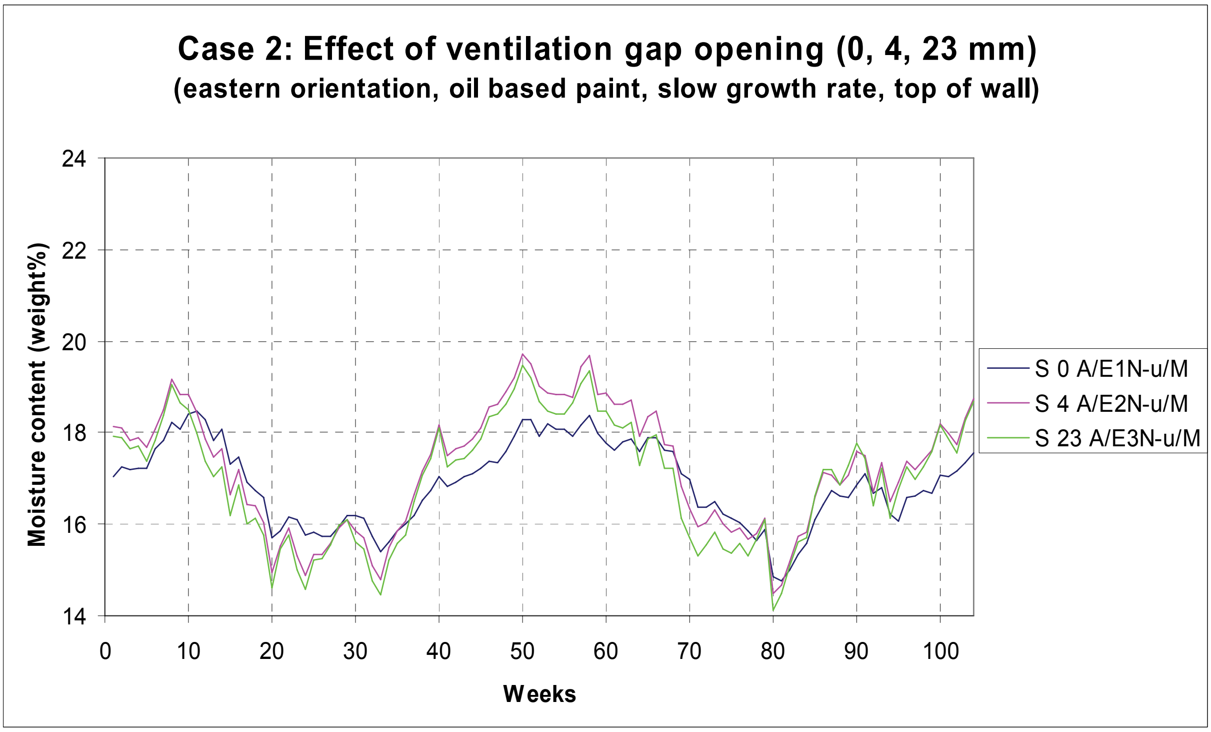
Regarding the driving rain measurement gauges on the walls (case 38-40) the last identifier after test section identifier refers to the location (height) on the wall (n = bottom part of wall, m = middle part of wall, o = top part of wall, ø = extra measurement on top part of wall).

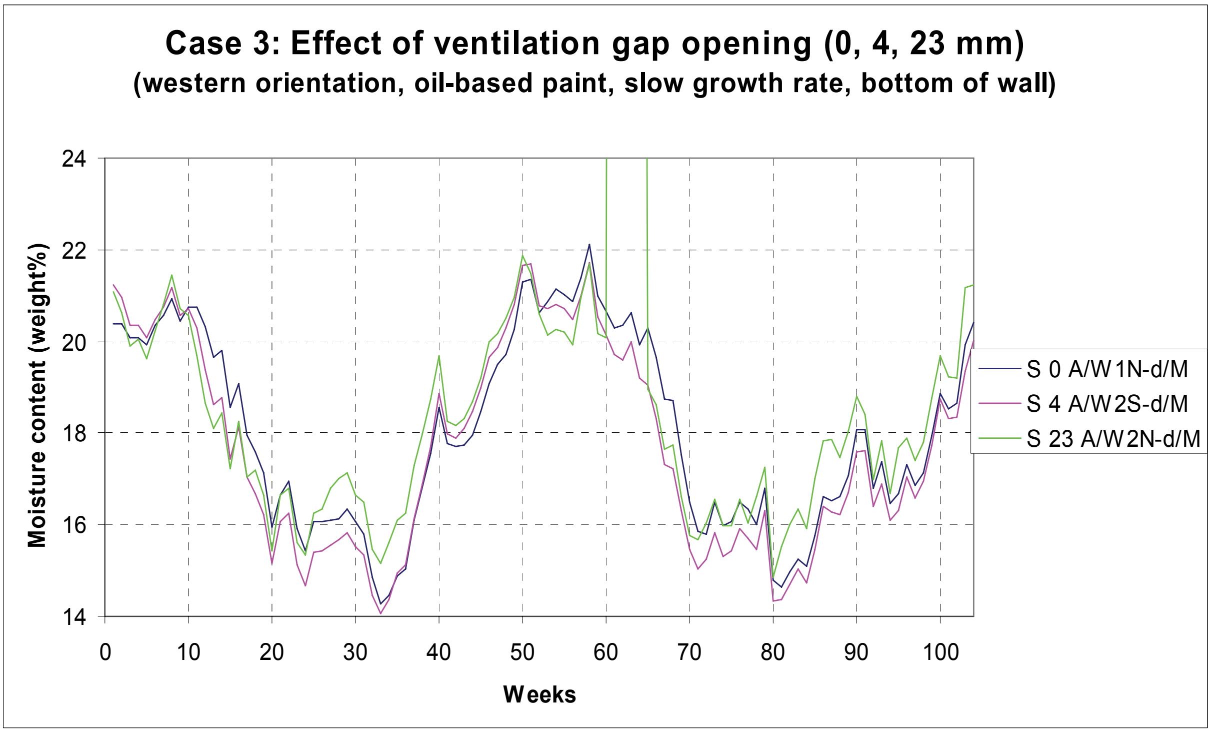
Table A4.2
Description of Cases

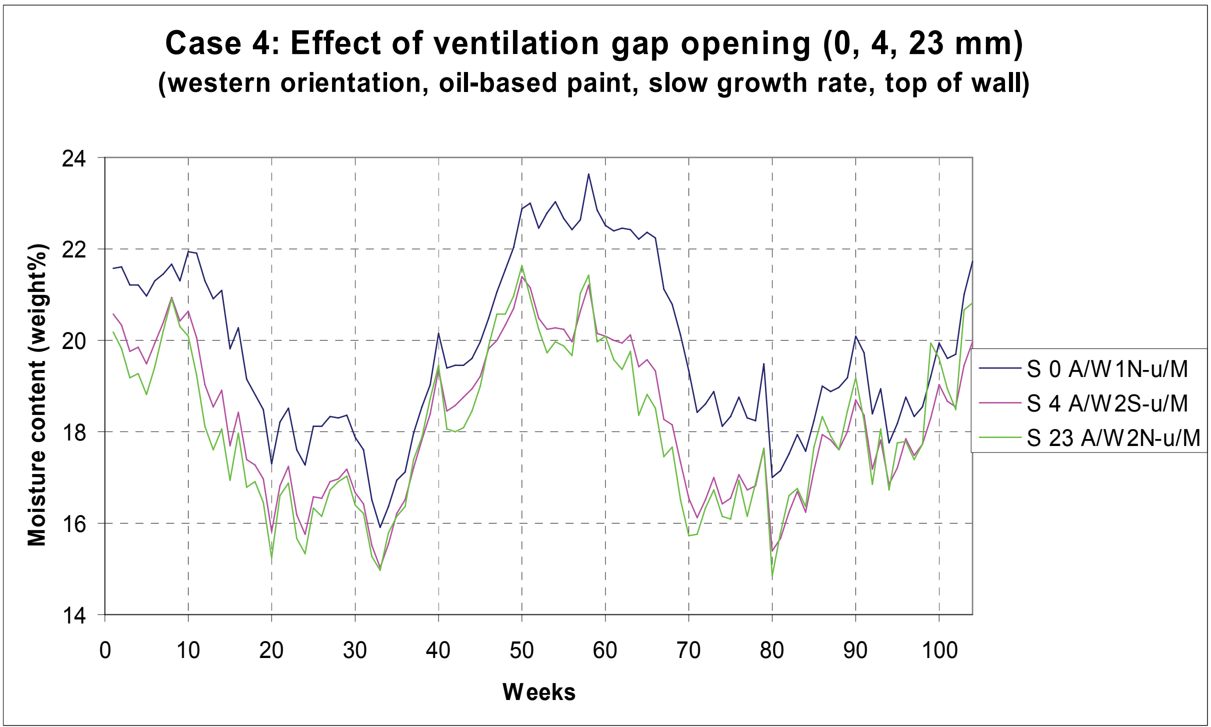
Case	Description	Sections	Parameter	Comments
	EFFECT OF VENTILATION OPENINGS			
1/2	0/4/23 mm: Eastern, oil based, slow	E1-N, E2-N, E3-N	MC	Top (2) + down (1)
3/4	0/4/23 mm: Western, oil based, slow	W1-N,W2-S, W2-N	MC	Top (4) + down (3)
5/6	0/4/23 mm: Western, water based, slow	W4-S, W5-S, W7-S	MC	Top (6) + down (5)
7/8	0/4/23 mm: Western, oil based, fast	W4-N, W5-N, W7-N	MC	Top (8) + down (7) W5-N was modified May 2005, see Chapter 3.1
	VARIATION WITH HEIGHT OF WALL:			
9	Top/bottom: Western, 0 mm, oil based, slow	W1-N	MC	
10	Top/bottom: Western, 23 mm, oil based, slow	W2-N	MC	
11	Top/bottom: Eastern, 0 mm, oil based, slow	E1-N	MC	
12	Top/bottom: Eastern, 23 mm, oil based, slow	E3-N	MC	
12b	Top/bottom: Western, 0 mm, water based, slow	W4S	MC	
12c	Top/bottom: Western, 23 mm, water based, slow	W7S	MC	
12d	Top/bottom: Western, 0 mm, water based, fast	W4N	MC	
12e	Top/bottom: Western, 23 mm, water based, fast	W7N	MC	
12f	Top/bottom: Eastern, 0 mm, water based, slow	E5N	MC	
12g	Top/bottom: Eastern, 23 mm, water based, slow	E7N	MC	
	EFFECT OF SURFACE TREATMENT:			
13	Oil/water based: Western, 23 mm, slow, top	W2-N, W7-S	MC	
14	Oil/water based: Western, 0 mm, slow, top	W1-N, W4-S	MC	
15	Oil/water/untreated: Western, 4 mm, slow, top	W2-S, W5-S, W6-S	MC	
16	Oil/water/untreated: Eastern, 4 mm, slow, top	E2-N, E4-N, E6-N	MC	
	EFFECT OF DRIVING RAIN (ORIENTATION):			
17	Eastern/western: 23 mm, oil based, slow, top	W2-N, E3-N	MC	
18	Eastern/western: 0 mm, oil based, slow, top	W1-N, E1-N	MC	

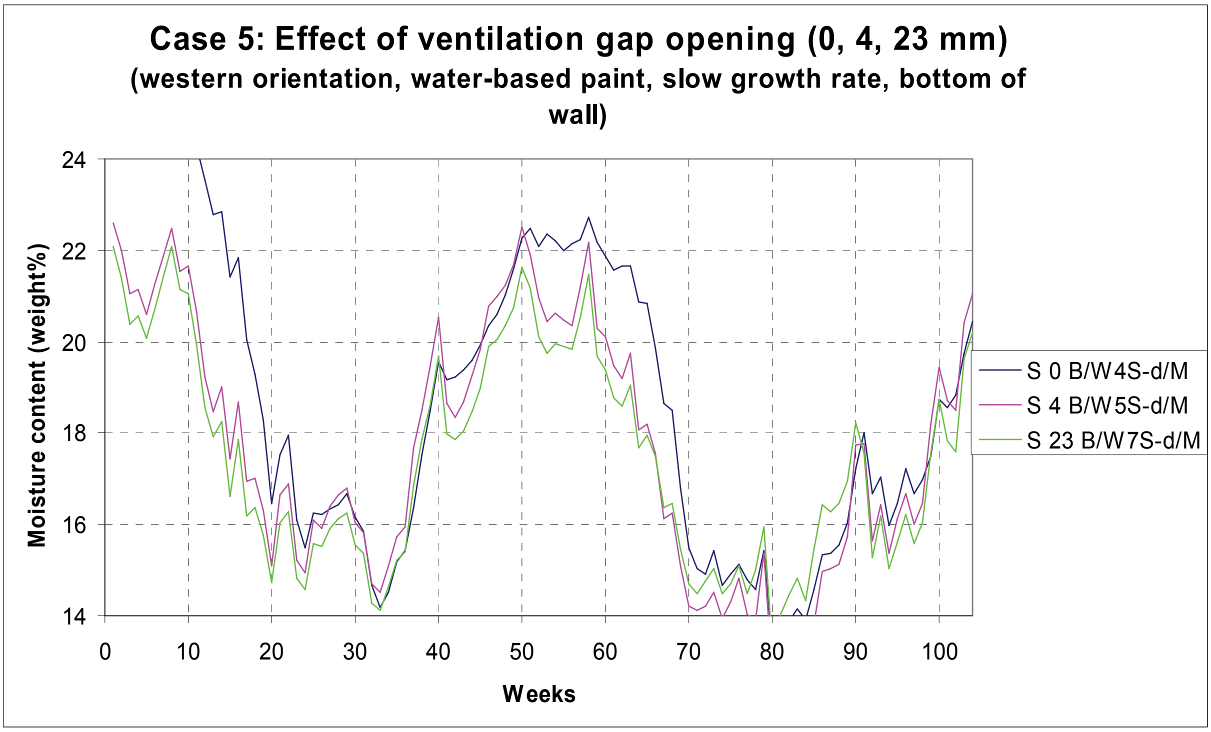
19	Eastern/western: 0 mm, water based, slow, top	W4-S, E5-N	MC	
20	Eastern/western: 4 mm, untreated, slow, top	W6-S, E4-N	MC	
	EFFECT OF GROWTH RATE:			
21	Slow/fast: Western, 23 mm, oil based, top	W2-N, W3-S	MC	
22	Slow/fast: Western, 0 mm, oil based, top	W1-N, W1-S	MC	
23	Slow/fast: Western, 23 mm, water based, top	W7-S, W7-N	MC	
24	Slow/fast: Eastern, 23 mm, oil based, top	E3-N, E3-S	MC	
25	Slow/fast: Western, 4 mm, untreated, top	W3-N, W6-S	MC	
	TEMPERATURE MEASUREMENTS:			
26	Temperature variation depth	W3-S	T (all)	Bottom
27	Temperature variation depth	W3-S	T (all)	Top
27b	Temperature variation depth	W6N	T (all)	Top
27c	Temperature variation depth	E4S	T (all)	Top
28	Temperature variation height	W3-S	T in cladding and air gap	Bottom + top
29	Temperature variation east/west	W2-S, E2-N, W5-S, E6-N	T in cladding	Top
30	0/4/23 mm: Eastern, oil based, slow	E1-N, E2-N, E3-N	T in cladding	Top
	MC VARIATIONS OVER CLADDING:			
31	MC variation depth	W3-S	MC (all)	Bottom
32	MC variation depth	W3-S	MC (all)	Top
32b	MC variation depth	W6N	MC (all)	Bottom
32c	MC variation depth	W6N	MC (all)	Top
33	MC variation depth	E4-S	MC (all)	Top
34	MC variation depth	E4-S	MC (all)	Bottom
35	MC variation depth	W2-N	MC (all)	Top
36	MC variation depth	W2-N	MC (all)	Bottom
	DRIVING RAIN MEASUREMENTS:			
37	Directional driving rain gauges (S, W, N, E)			Week
38	Driving rain gauges on wall (middle, W + E)	W3-N, W6-S, WN,E4-N, EN	mm/week	Week
39	Driving rain gauges on wall (variation with height)	W3-N	mm/week	Week
40	Driving rain gauges on wall (variation with height)	WN	mm/week	Week
	VARIOUS			
41	RH in air gaps	W1-N, W2-S, W2-N, E1-N, E3-N		Week
42	All MC measurements, west	W1-W7	MC	Top+bottom
43	All MC measurements, east	E1-E7	MC	Top + bottom

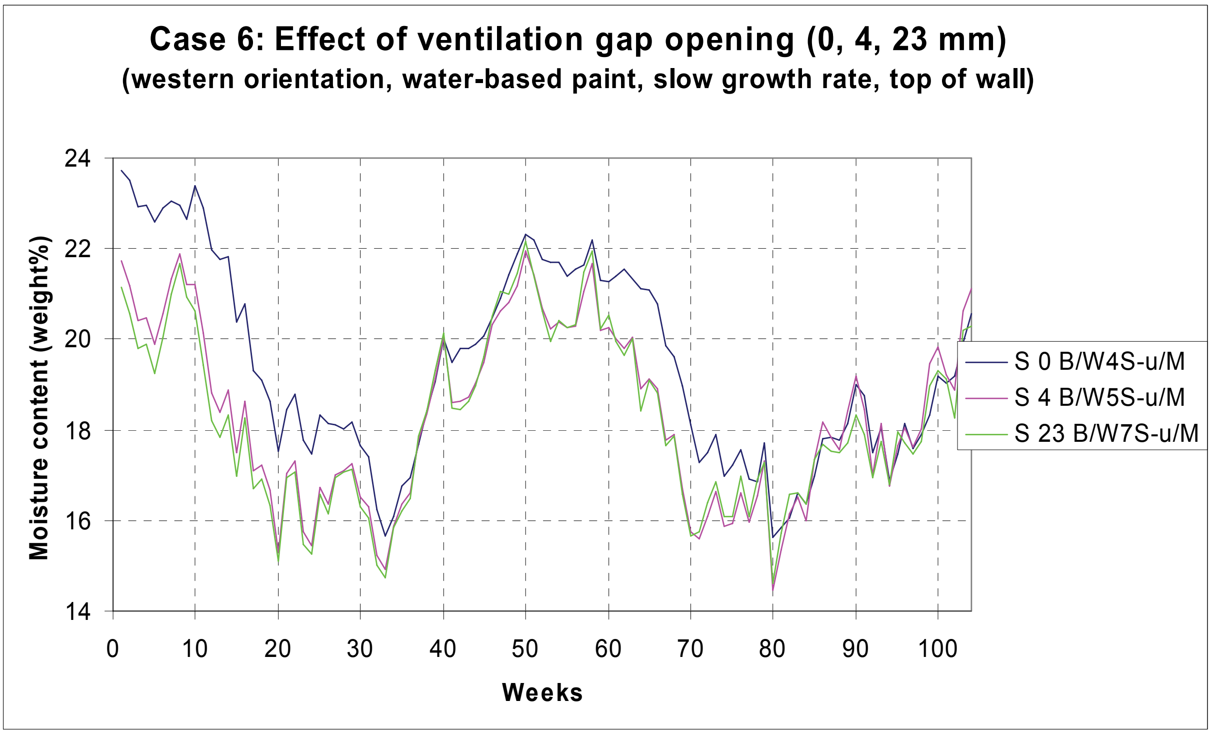

Case 1: Effect of ventilation gap opening (0, 4, 23 mm)
(eastern orientation, oil based paint, slow growth rate , bottom of wall)
Moisture content (weight%)
Weeks
4 mm
23 mm
0 mm
S 0 A/E1N-d/M
S 4 A/E2N-d/M
S 23 A/E3N-d/M

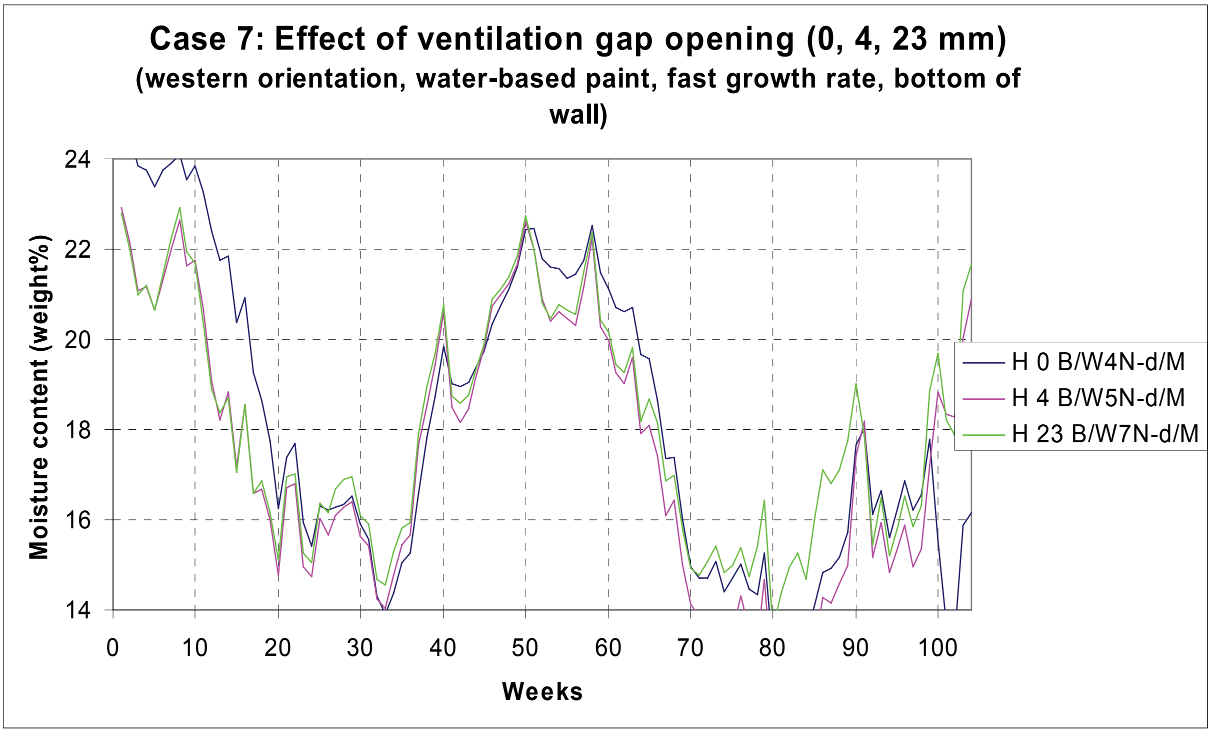

Case 2: Effect of ventilation gap opening (0, 4, 23 mm)
(eastern orientation, oil based paint, slow growth rate, top of wall)
Moisture content (weight%)
Weeks
S 0 A/E1N-u/M
S 4 A/E2N-u/M
S 23 A/E3N-u/M

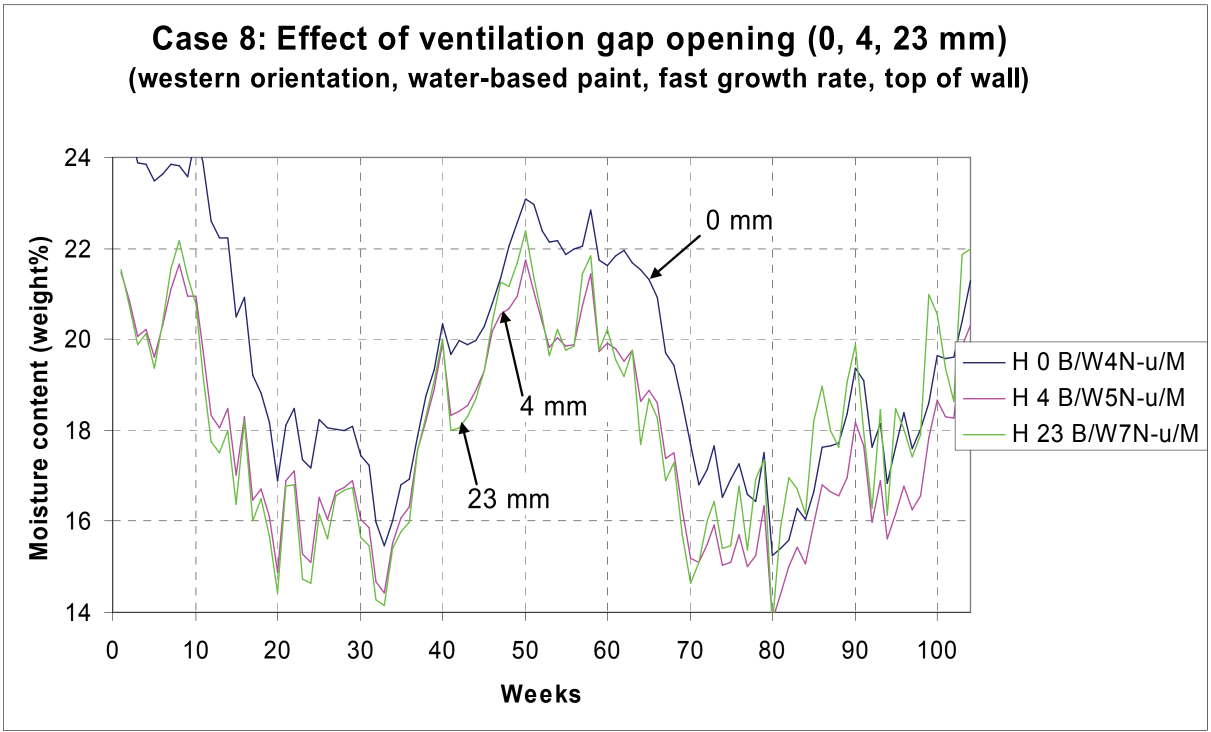

Case 3: Effect of ventilation gap opening (0, 4, 23 mm)
(western orientation, oil-based paint, slow growth rate, bottom of wall)
Moisture content (weight%)
Weeks
S 0 A/W1N-d/M
S 4 A/W2S-d/M
S 23 A/W2N-d/M

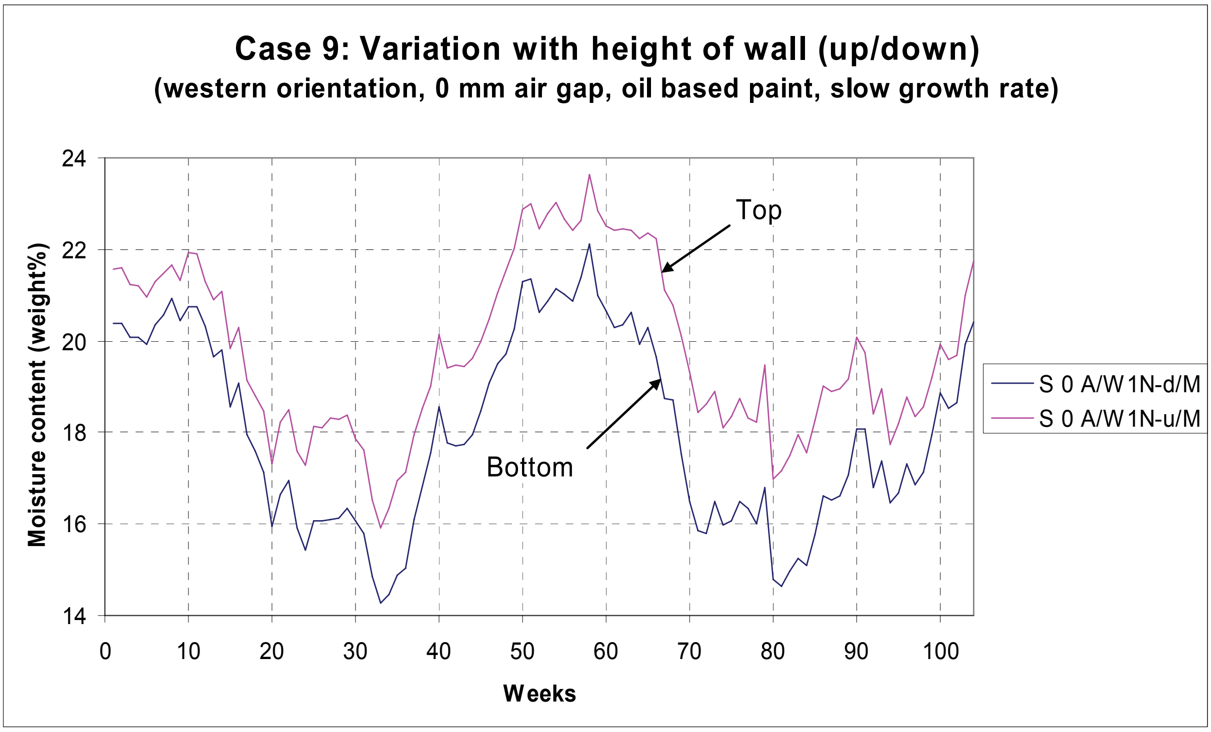

Case 4: Effect of ventilation gap opening (0, 4, 23 mm)
(western orientation, oil-based paint, slow growth rate, top of wall)
Moisture content (weight%)
Weeks
S 0 A/W1N-u/M
S 4 A/W2S-u/M
S 23 A/W2N-u/M

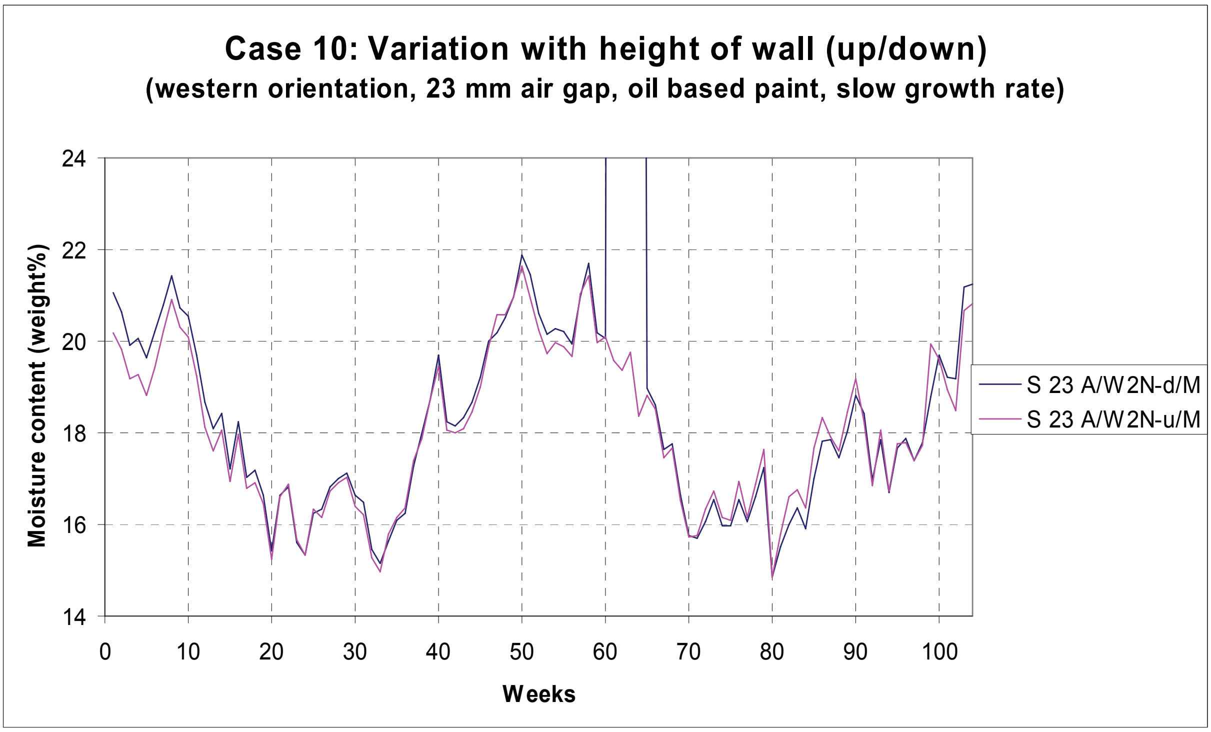

Case 5: Effect of ventilation gap opening (0, 4, 23 mm)
(western orientation, water-based paint, slow growth rate, bottom of wall)
Moisture content (weight%)
Weeks
S 0 B/W4S-d/M
S 4 B/W5S-d/M
S 23 B/W7S-d/M

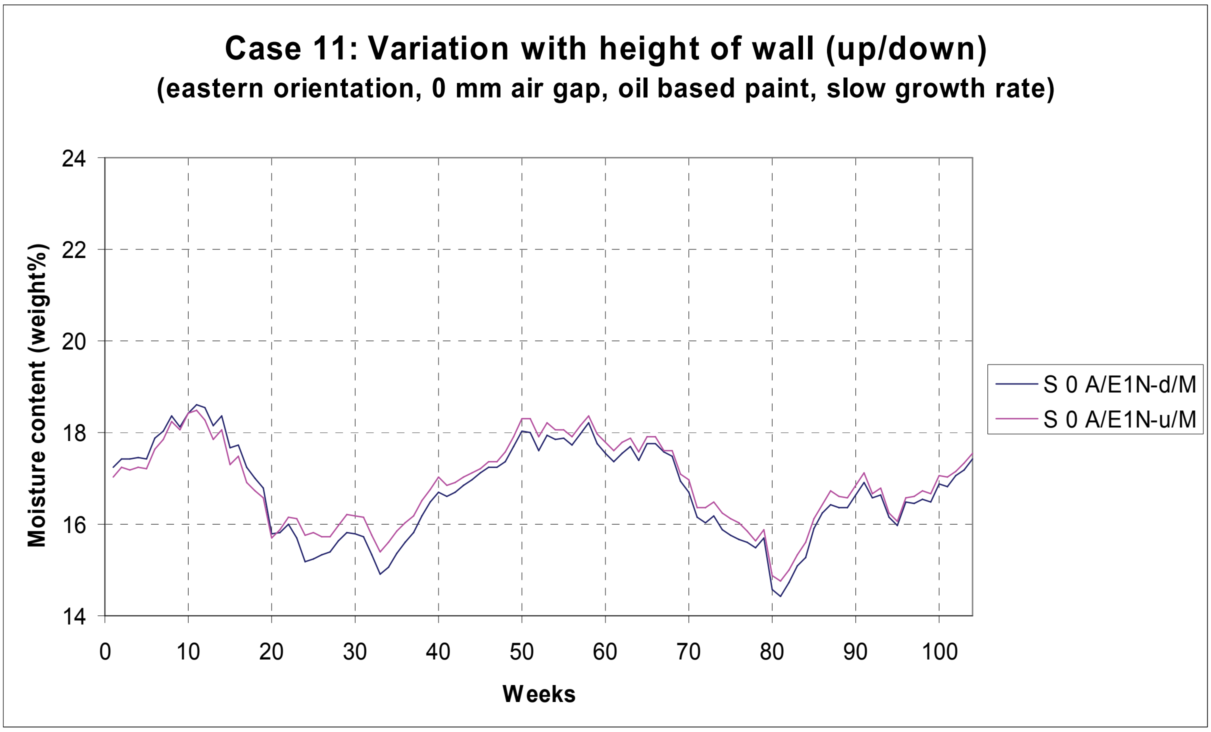

Case 6: Effect of ventilation gap opening (0, 4, 23 mm)
(western orientation, water-based paint, slow growth rate, top of wall)
Moisture content (weight%)
Weeks
S 0 B/W4S-u/M
S 4 B/W5S-u/M
S 23 B/W7S-u/M

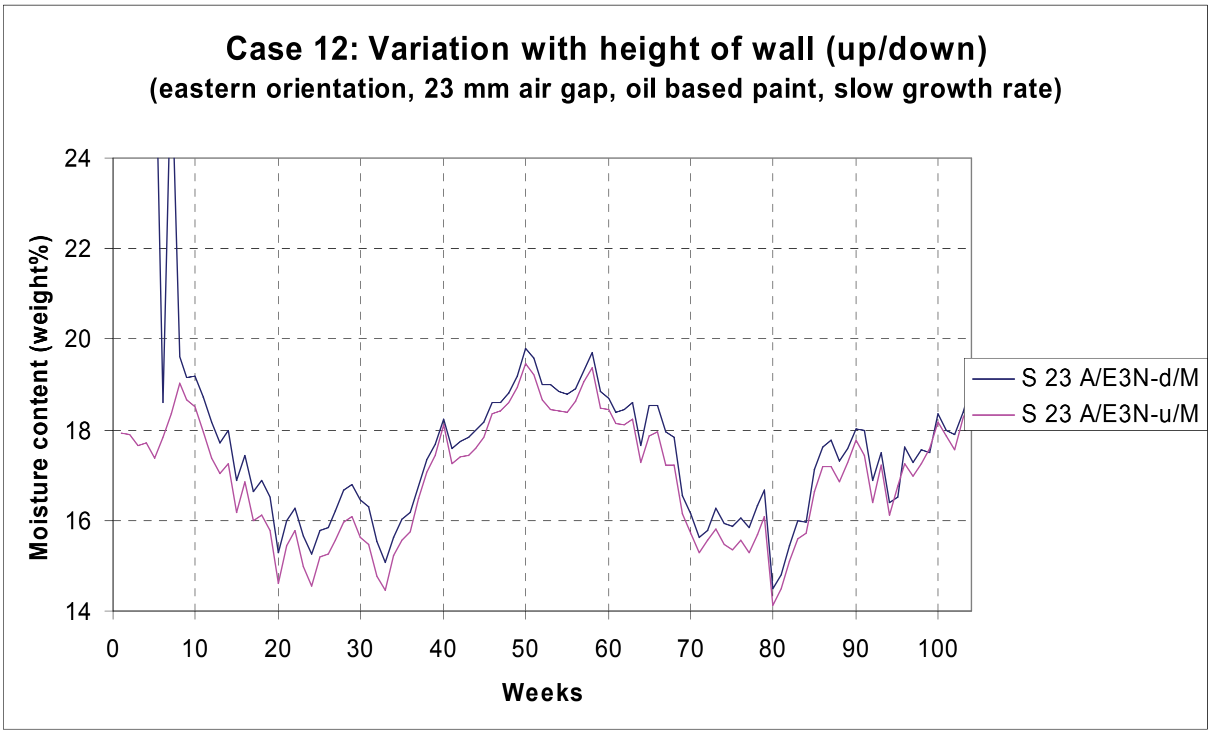

Case 7: Effect of ventilation gap opening (0, 4, 23 mm)
(western orientation, water-based paint, fast growth rate, bottom of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 0 B/W4N-d/M
H 4 B/W5N-d/M
H 23 B/W7N-d/M

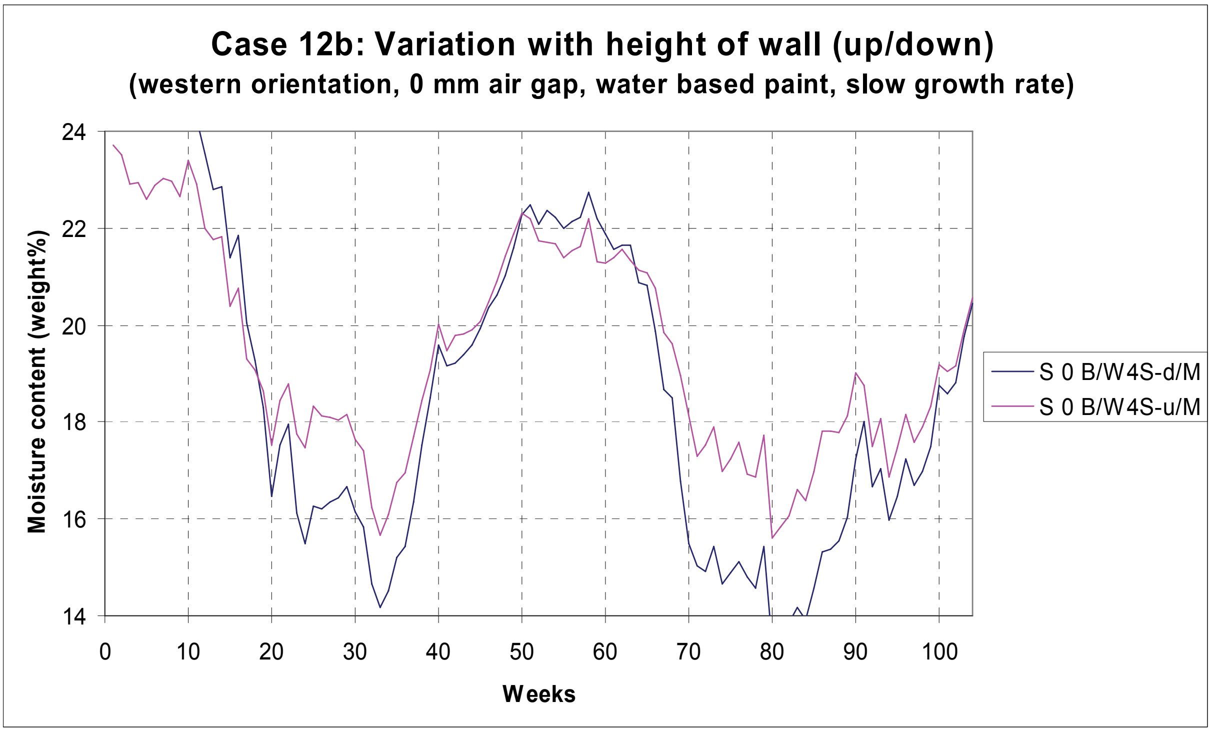

Case 8: Effect of ventilation gap opening (0, 4, 23 mm)
(western orientation, water-based paint, fast growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
0 mm
4 mm
23 mm
H 0 B/W4N-u/M
H 4 B/W5N-u/M
H 23 B/W7N-u/M

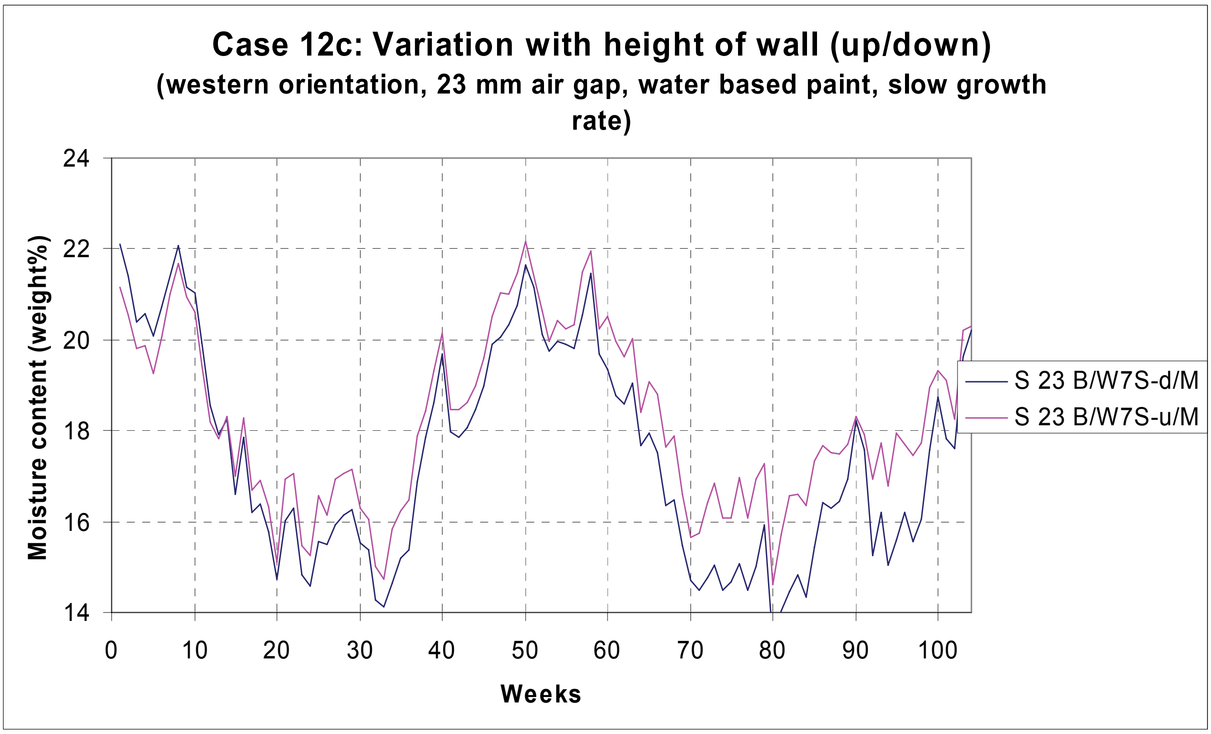

Case 9: Variation with height of wall (up/down)
(western orientation, 0 mm air gap, oil based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
Top
Bottom
S 0 A/W1N-d/M
S 0 A/W1N-u/M

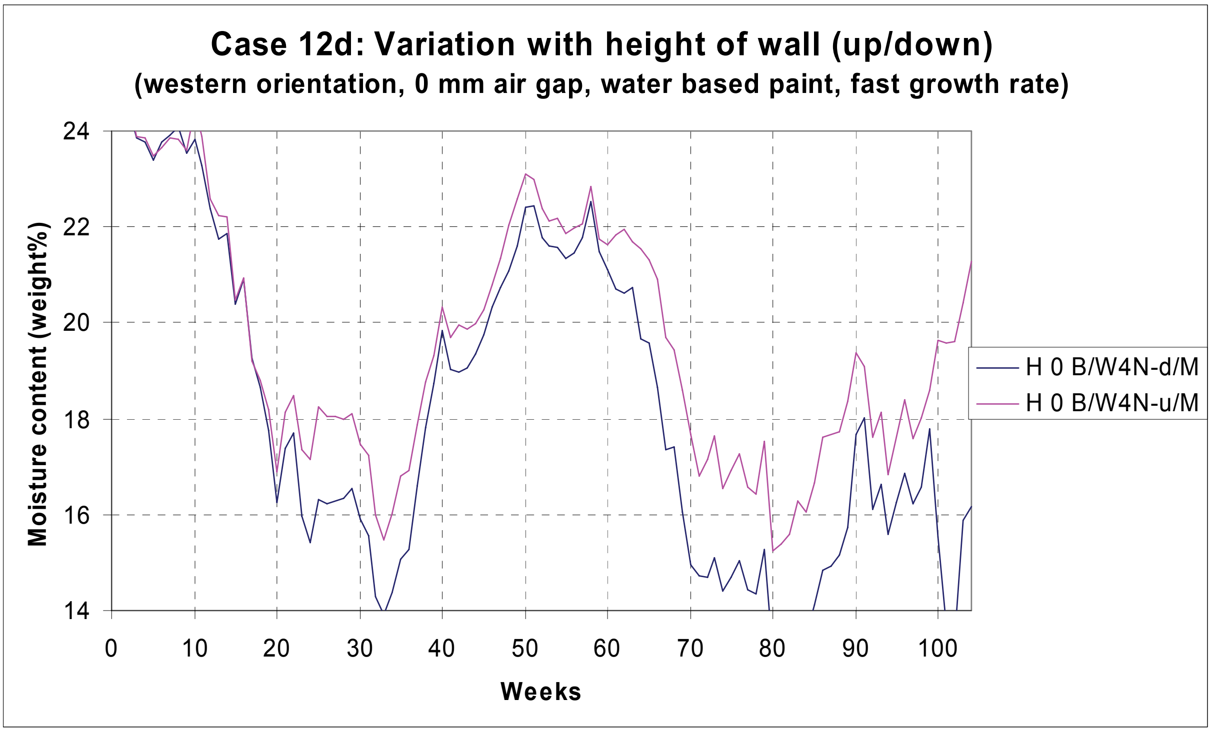

Case 10: Variation with height of wall (up/down)
(western orientation, 23 mm air gap, oil based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 23 A/W2N-d/M
S 23 A/W2N-u/M

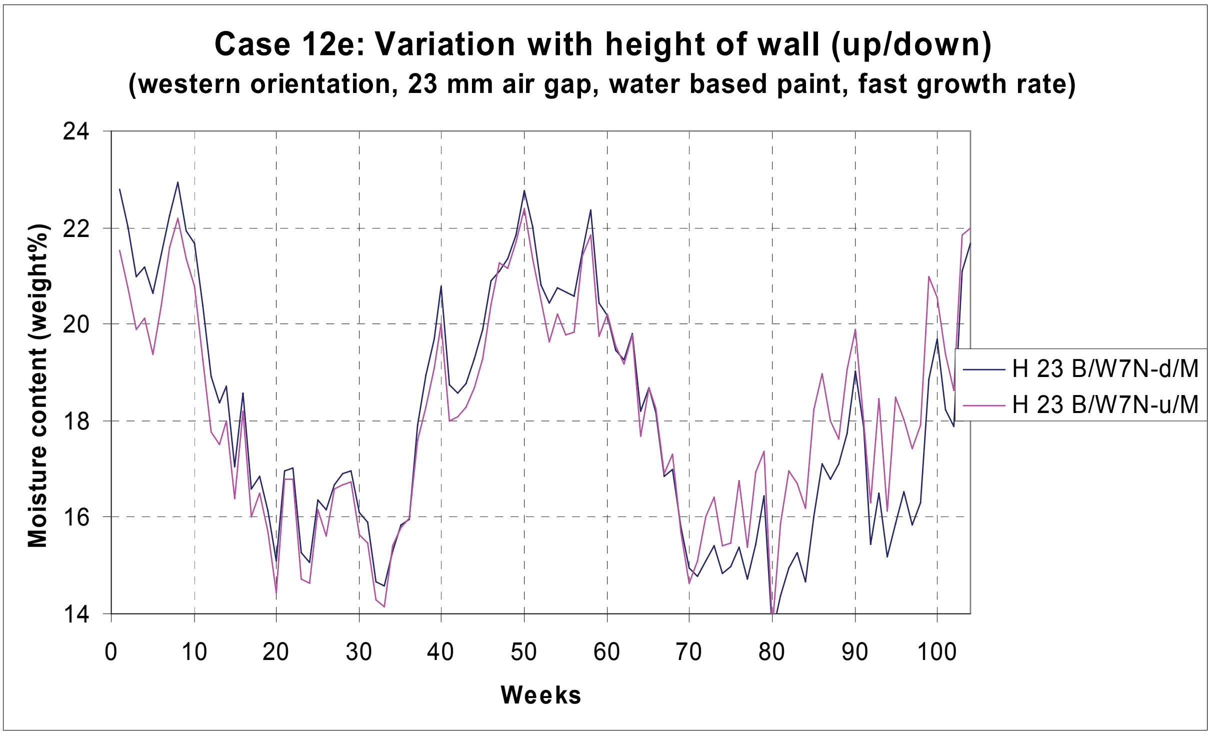

Case 11: Variation with height of wall (up/down)
(eastern orientation, 0 mm air gap, oil based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 0 A/E1N-d/M
S 0 A/E1N-u/M

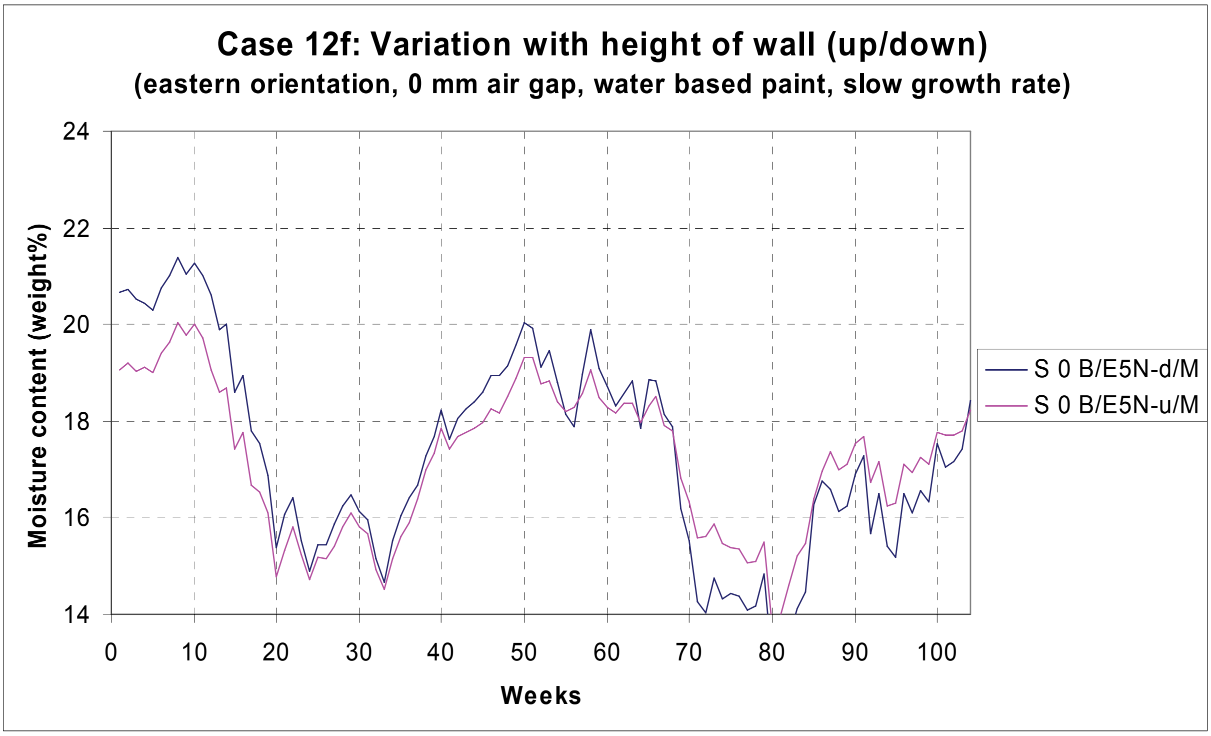

Case 12: Variation with height of wall (up/down)
(eastern orientation, 23 mm air gap, oil based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 23 A/E3N-d/M
S 23 A/E3N-u/M

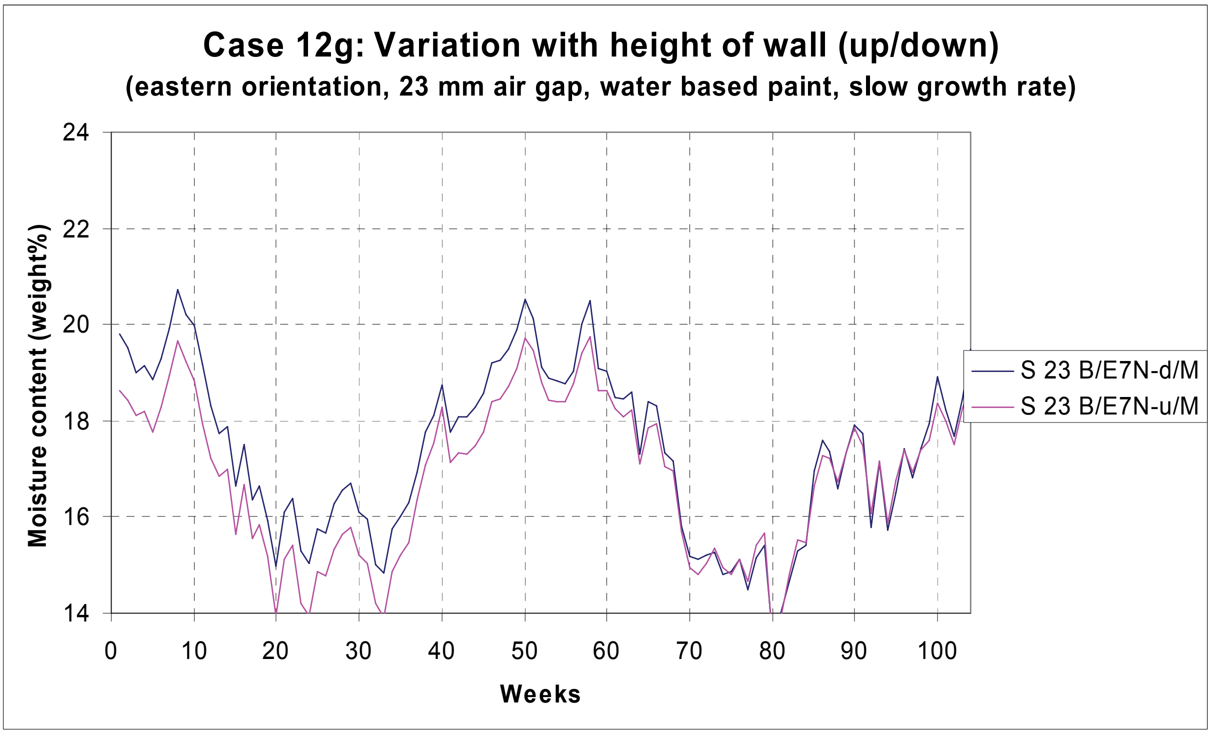

Case 12b: Variation with height of wall (up/down)
(western orientation, 0 mm air gap, water based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 0 B/W4S-d/M
S 0 B/W4S-u/M

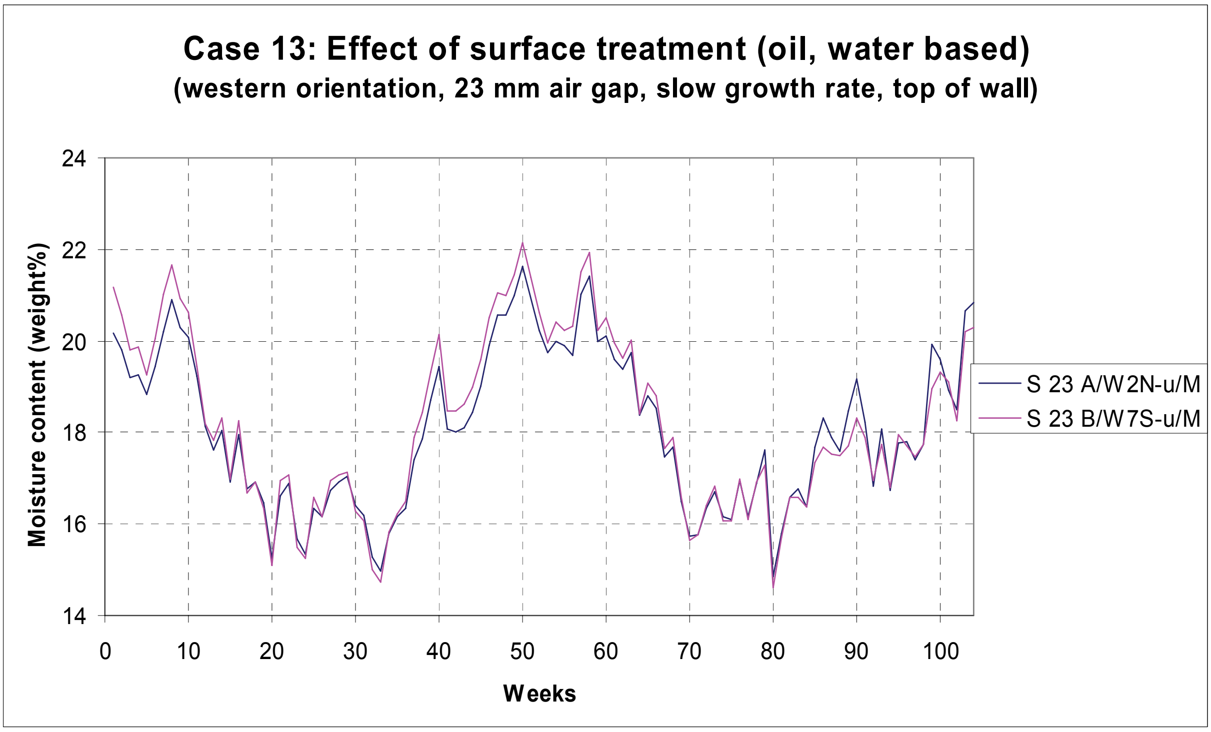

Case 12c: Variation with height of wall (up/down)
(western orientation, 23 mm air gap, water based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 23 B/W7S-d/M
S 23 B/W7S-u/M

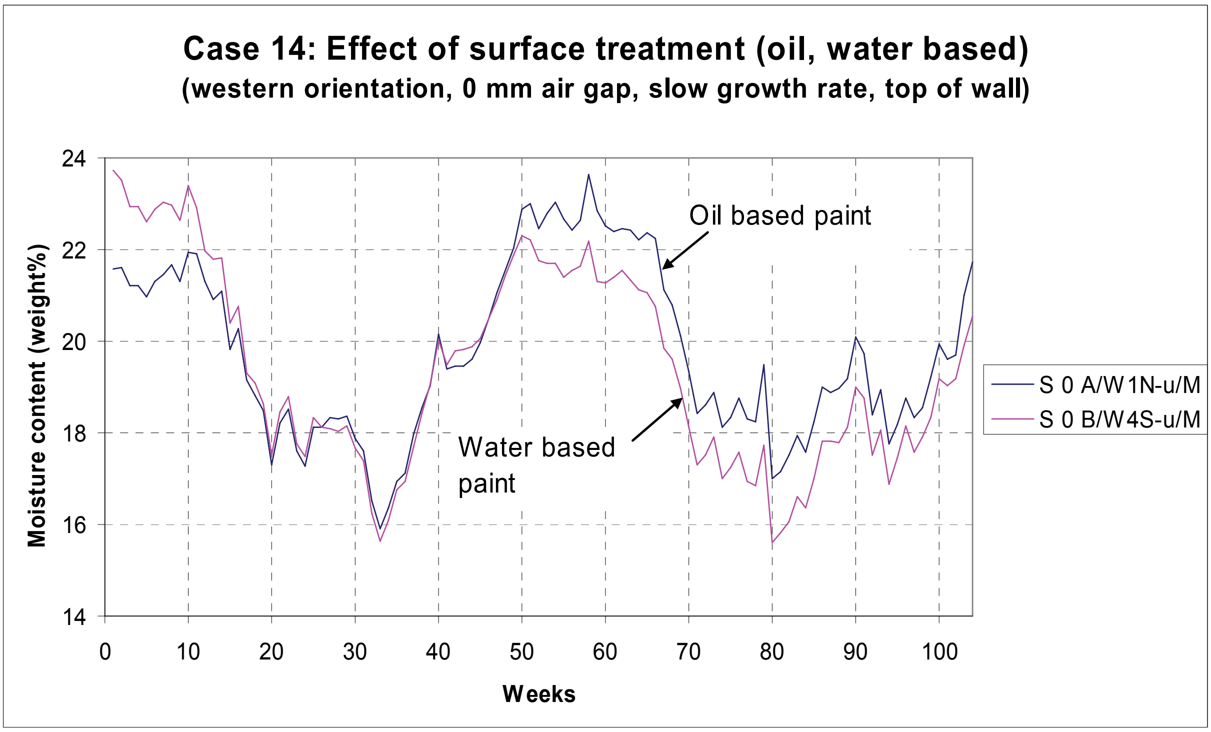

Case 12d: Variation with height of wall (up/down)
(western orientation, 0 mm air gap, water based paint, fast growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 0 B/W4N-d/M
H 0 B/W4N-u/M

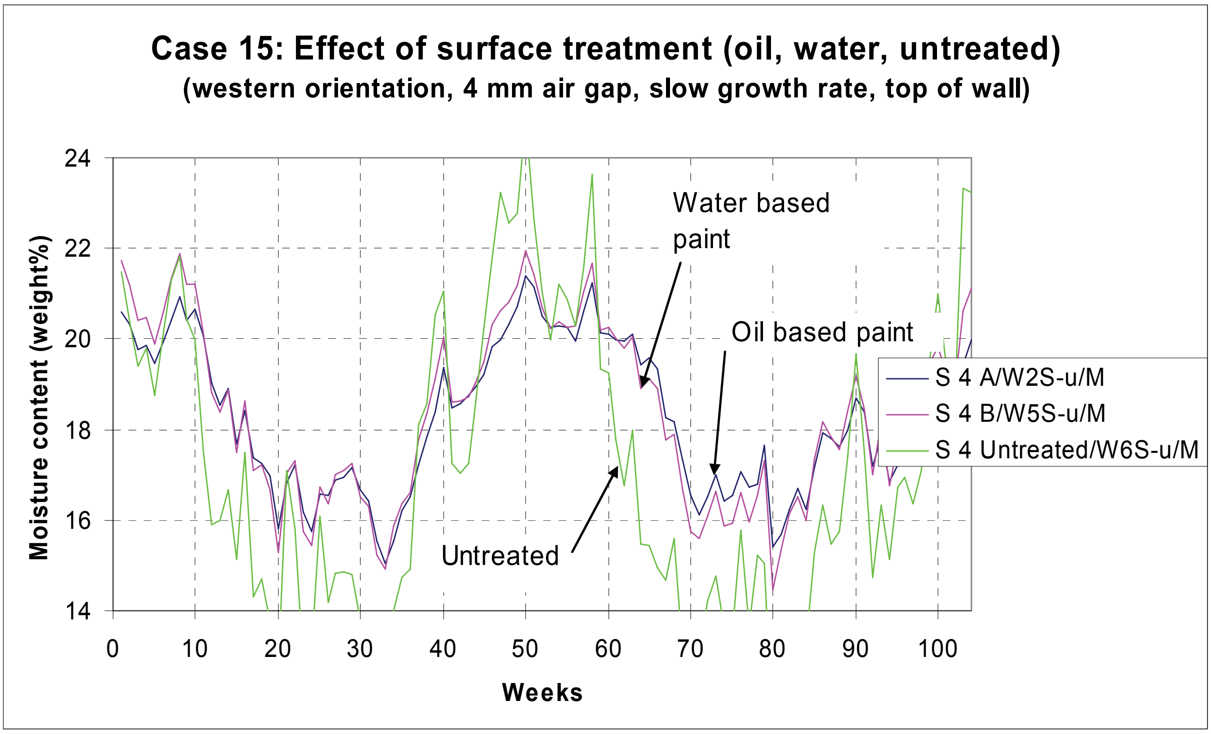

Case 12e: Variation with height of wall (up/down)
(western orientation, 23 mm air gap, water based paint, fast growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 23 B/W7N-d/M
H 23 B/W7N-u/M

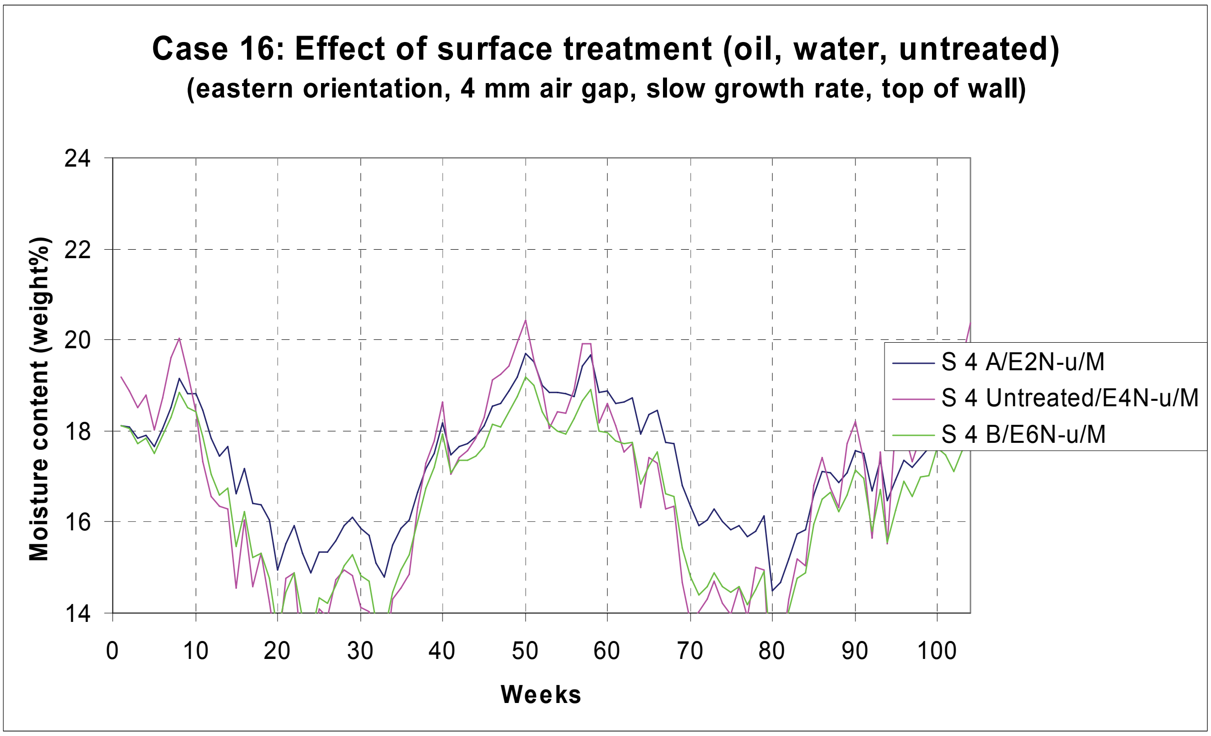

Case 12f: Variation with height of wall (up/down)
(eastern orientation, 0 mm air gap, water based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 0 B/E5N-d/M
S 0 B/E5N-u/M

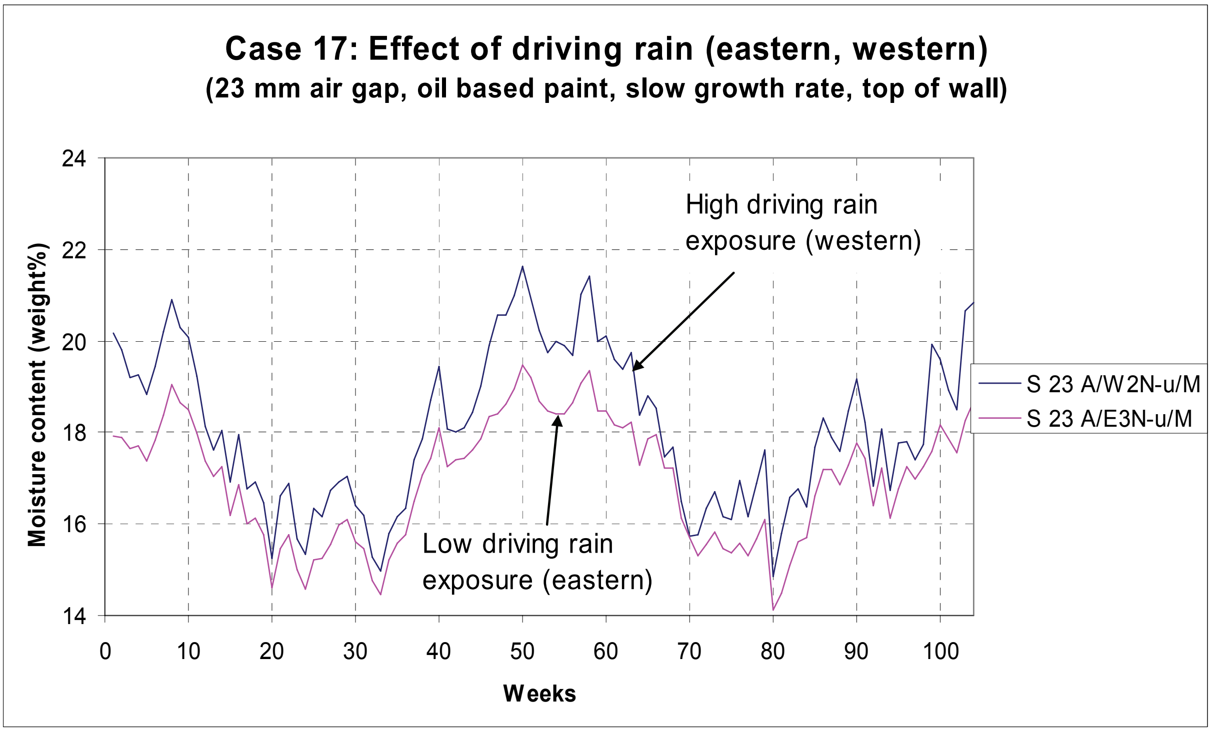

Case 12g: Variation with height of wall (up/down)
(eastern orientation, 23 mm air gap, water based paint, slow growth rate)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 23 B/E7N-d/M
S 23 B/E7N-u/M

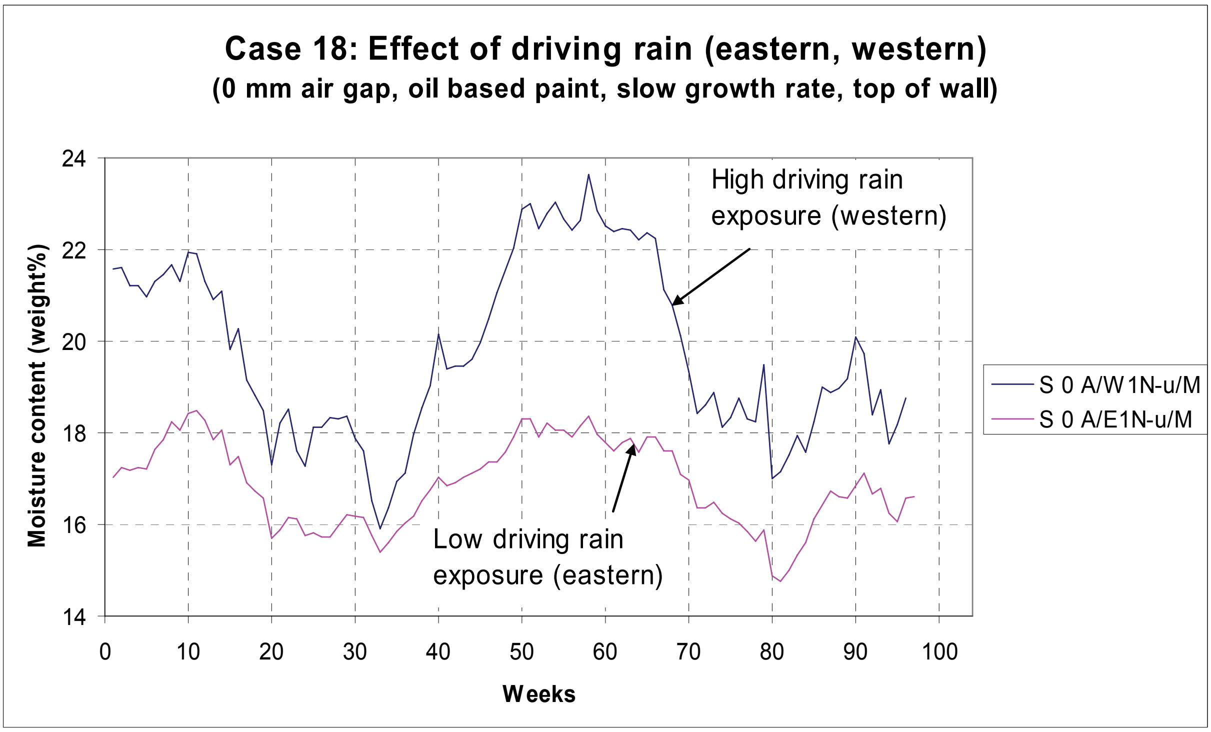

Case 13: Effect of surface treatment (oil, water based)
(western orientation, 23 mm air gap, slow growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 23 A/W2N-u/M
S 23 B/W7S-u/M

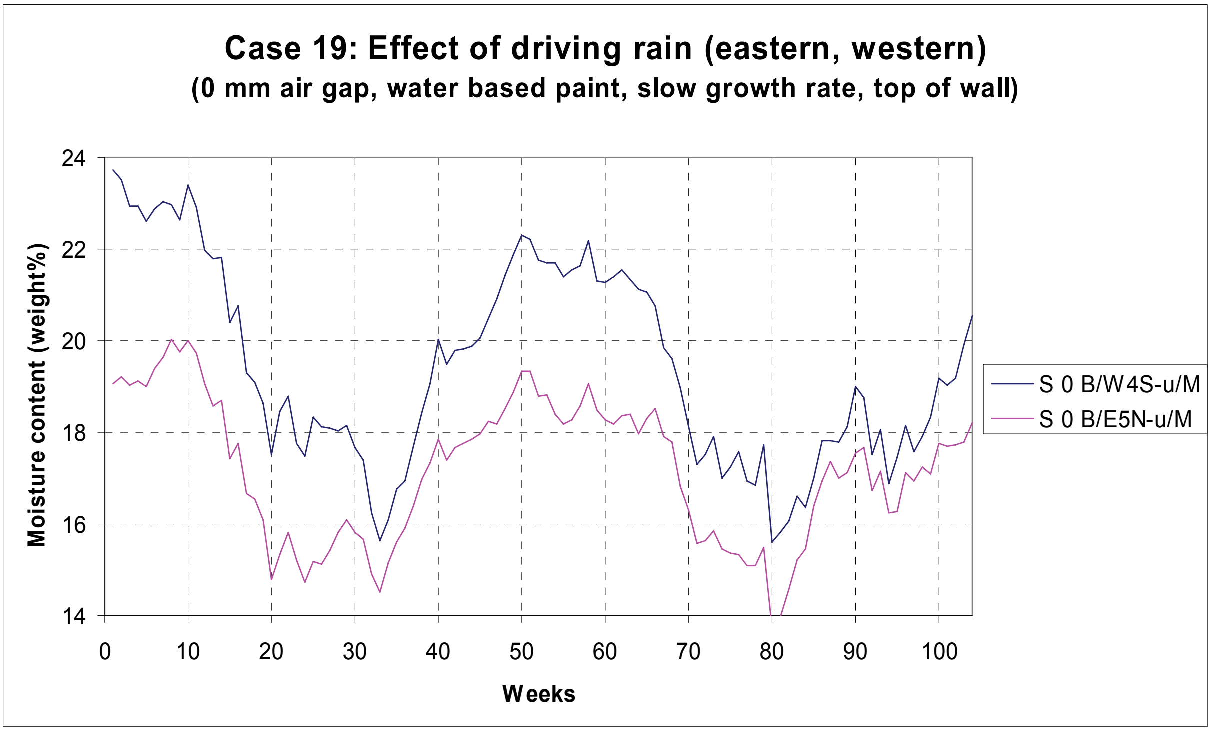

Case 14: Effect of surface treatment (oil, water based)
(western orientation, 0 mm air gap, slow growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
Oil based paint
Water based paint
S 0 A/W1N-u/M
S 0 B/W4S-u/M

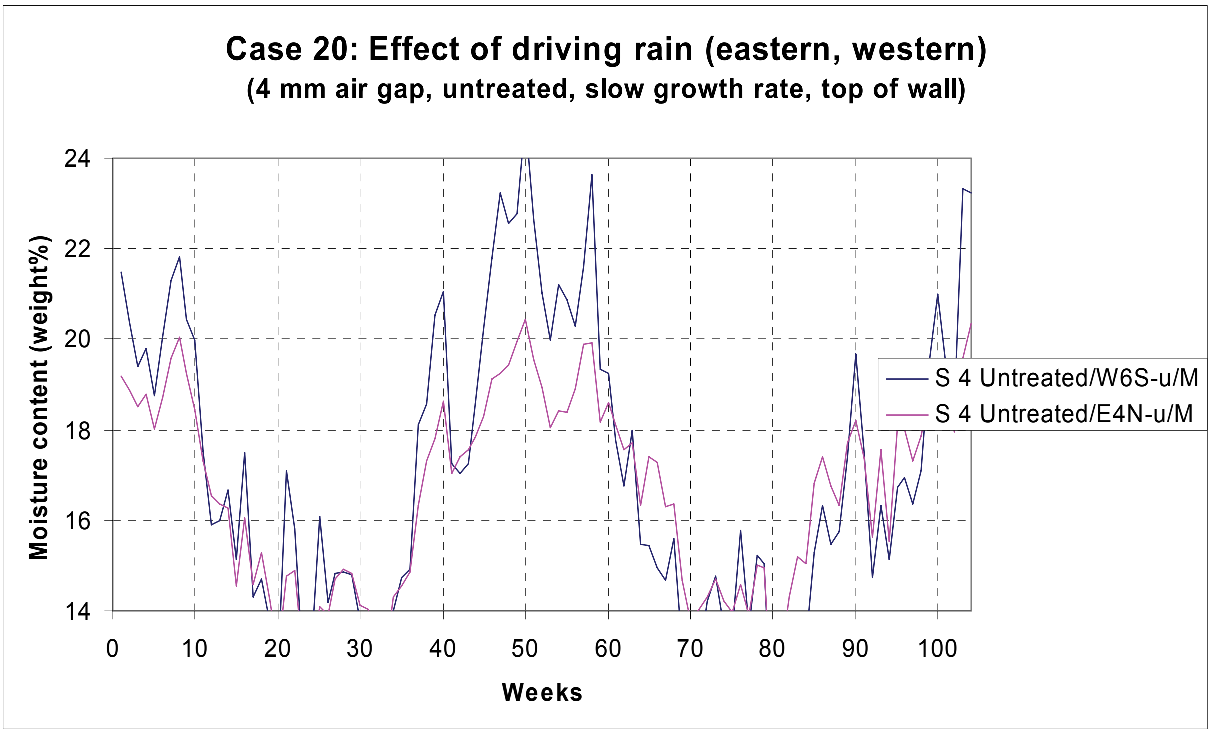

Case 15: Effect of surface treatment (oil, water, untreated)
(western orientation, 4 mm air gap, slow growth rate, top of wall)
Moisture content (weight%)
Weeks
Water based paint
Oil based paint
Untreated
S 4 A/W2S-u/M
S 4 B/W5S-u/M
S 4 Untreated/W6S-u/M

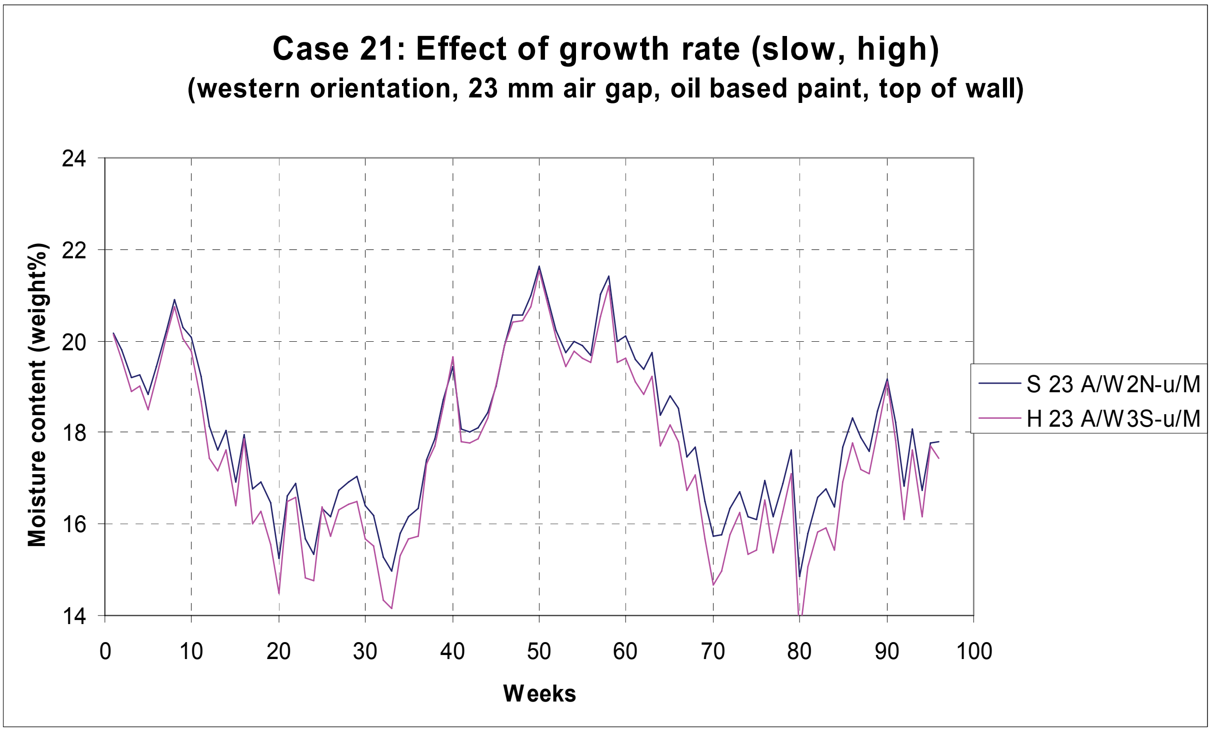

Case 16: Effect of surface treatment (oil, water, untreated)
(eastern orientation, 4 mm air gap, slow growth rate, top of wall)
Moisture content (weight%)
Weeks
S 4 A/E2N-u/M
S 4 Untreated/E4N-u/M
S 4 B/E6N-u/M

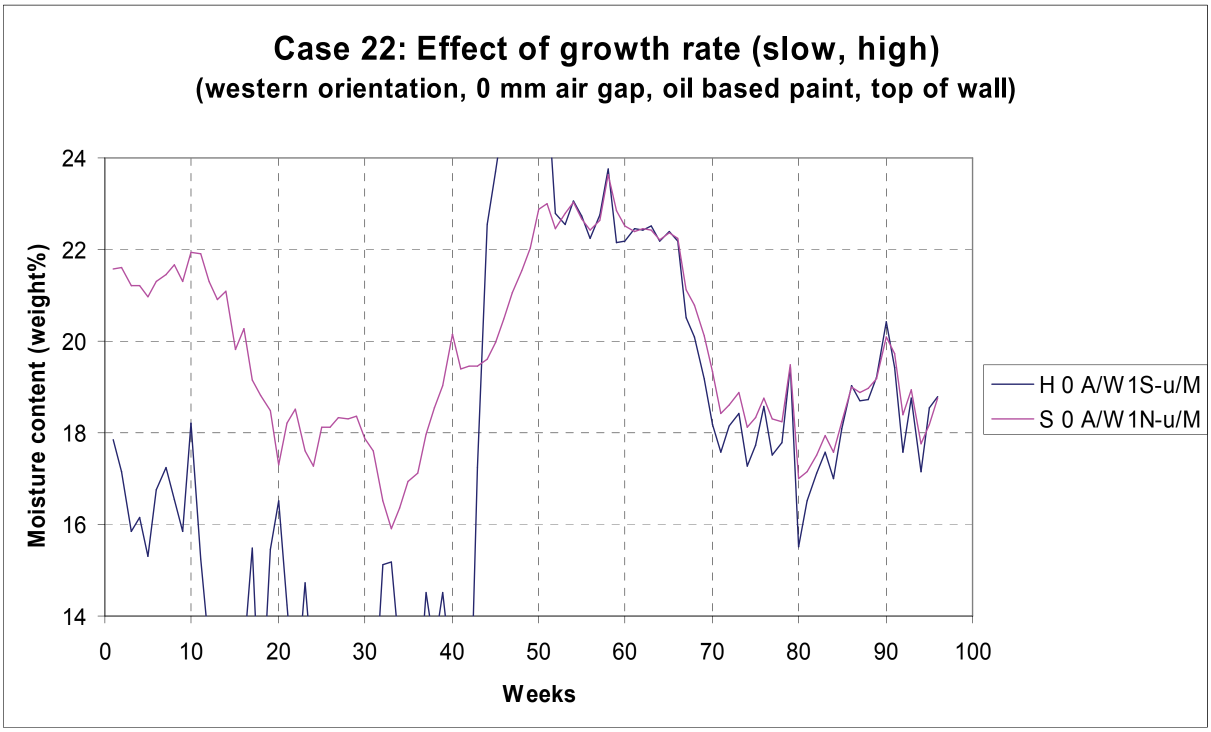

Case 17: Effect of driving rain (eastern, western)
(23 mm air gap, oil based paint, slow growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
High driving rain exposure (western)
Low driving rain exposure (eastern)
S 23 A/W2N-u/M
S 23 A/E3N-u/M


Case 18: Effect of driving rain (eastern, western)
(0 mm air gap, oil based paint, slow growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
High driving rain exposure (western)
Low driving rain exposure (eastern)
S 0 A/W1N-u/M
S 0 A/E1N-u/M

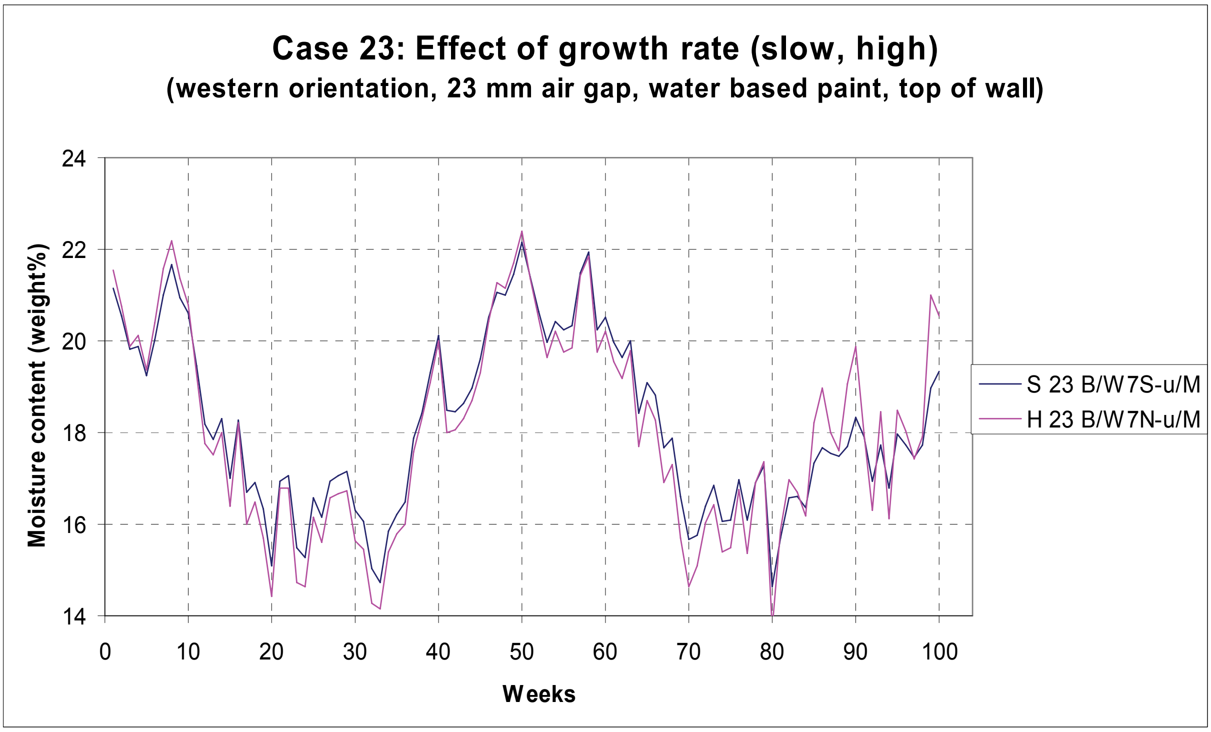

Case 19: Effect of driving rain (eastern, western)
(0 mm air gap, water based paint, slow growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 0 B/W4S-u/M
S 0 B/E5N-u/M

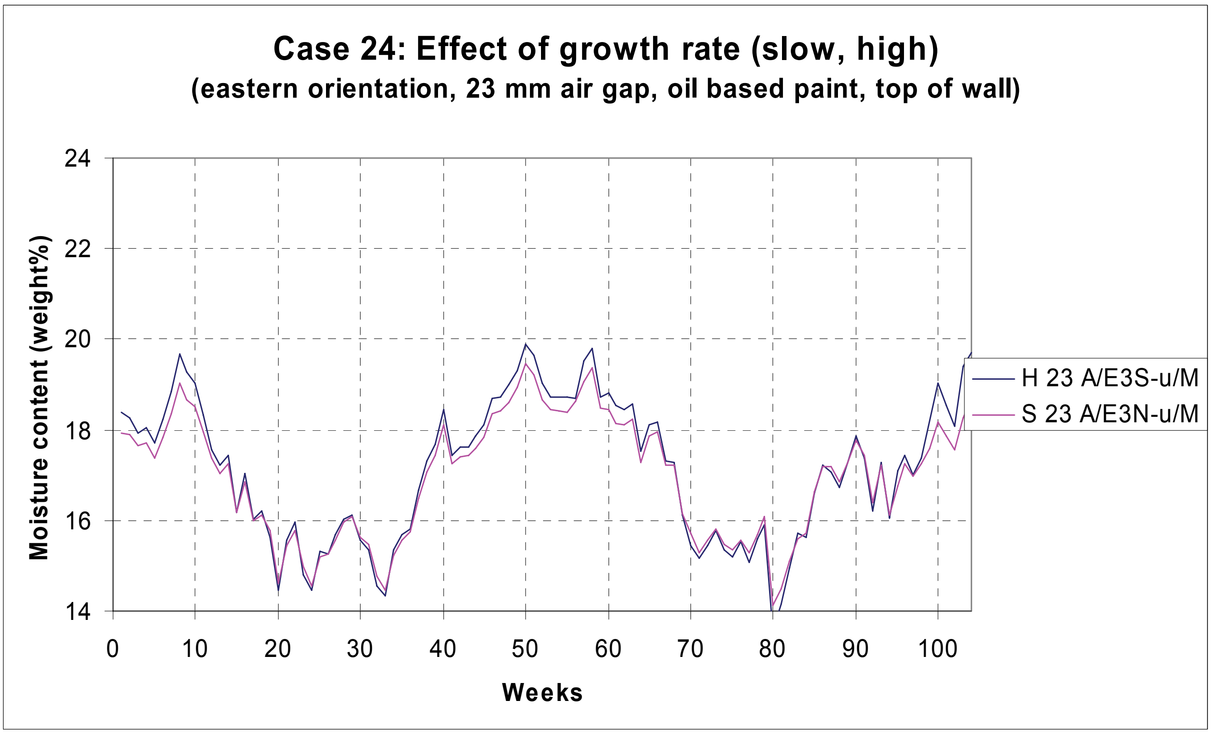

Case 20: Effect of driving rain (eastern, western)
(4 mm air gap, untreated, slow growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
S 4 Untreated/W6S-u/M
S 4 Untreated/E4N-u/M

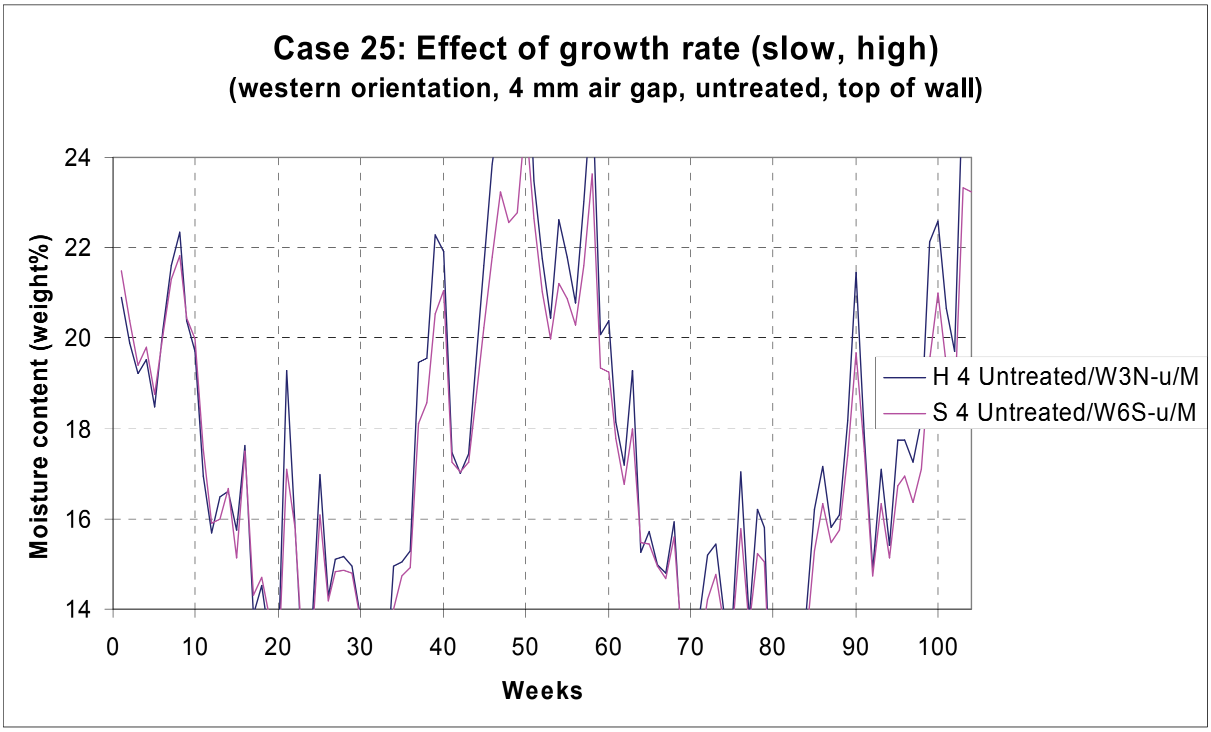


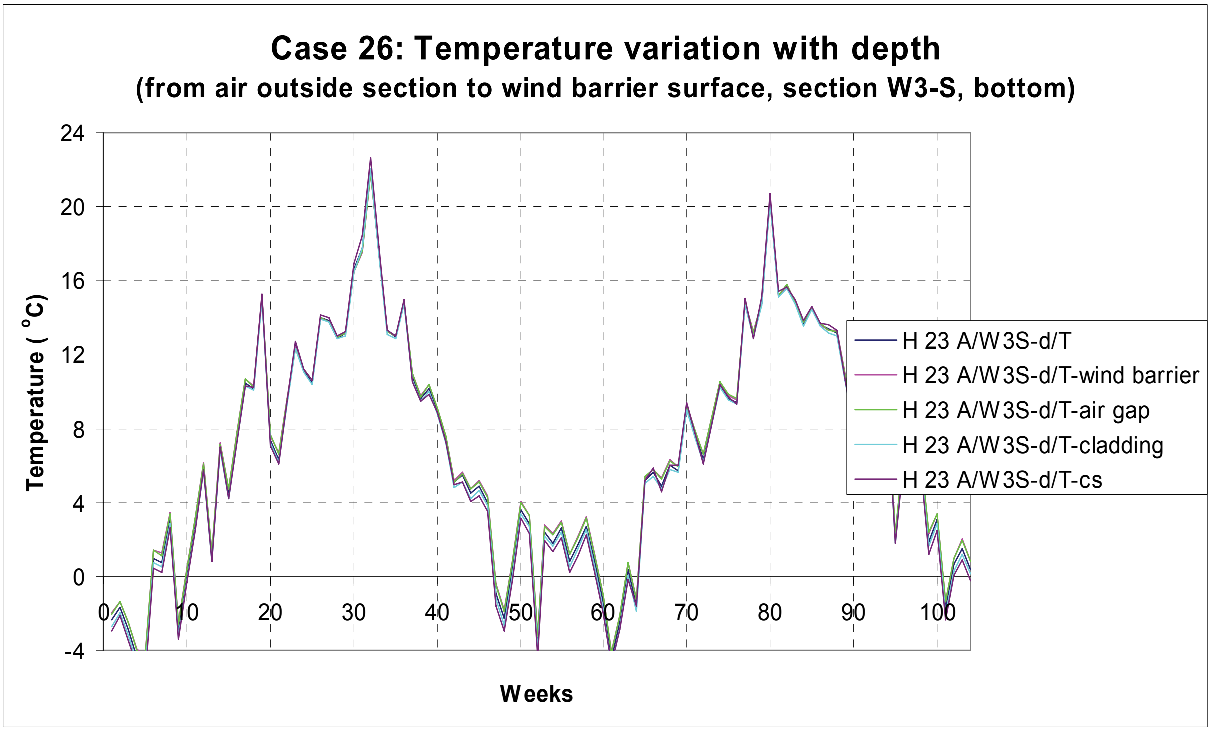


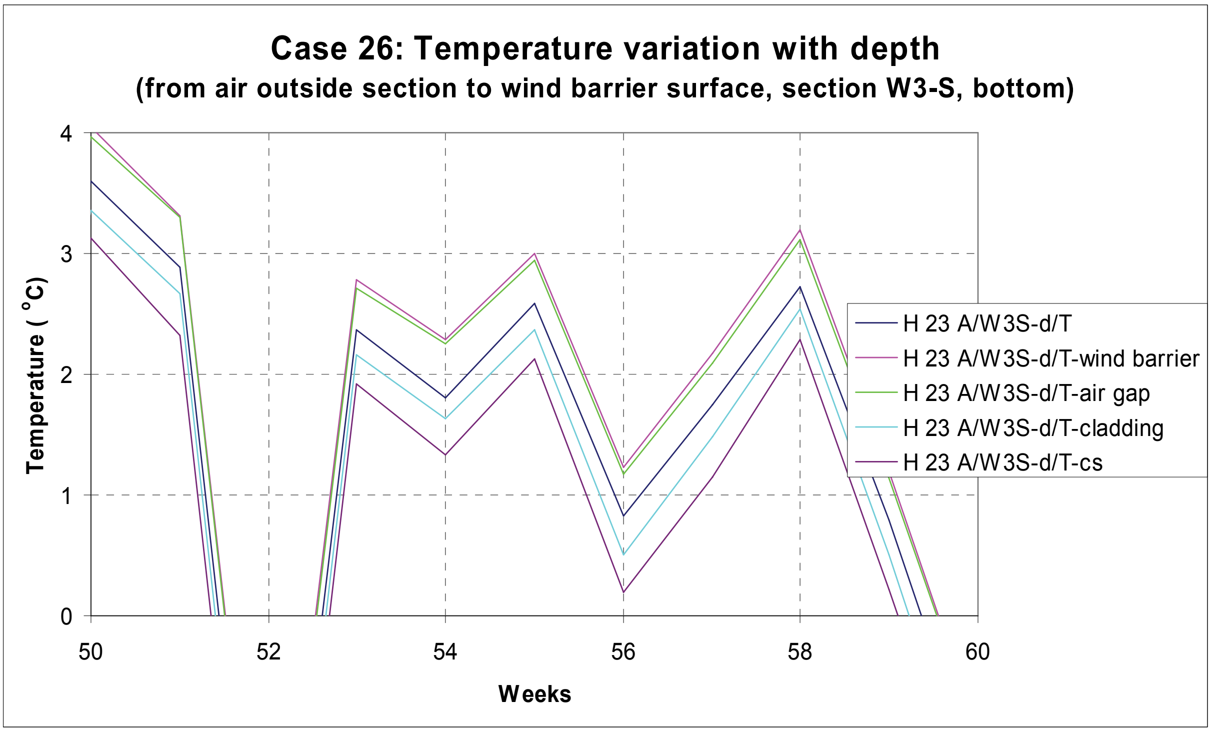
NOTE: There seem to be a measurement error occuring for W1S-u/M from week 0 – 50.

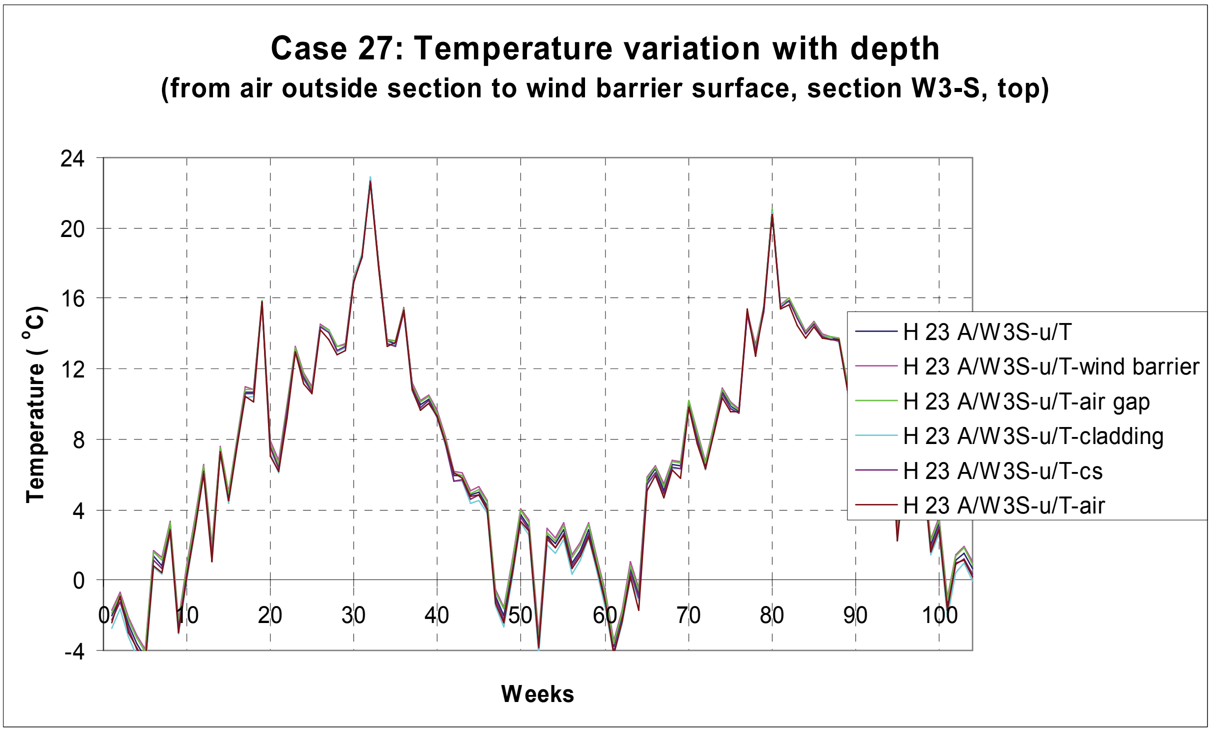

Case 23: Effect of growth rate (slow, high)
(western orientation, 23 mm air gap, water based paint, top of wall)
Moisture content (weight%)
Weeks
S 23 B/W7S-u/M
H 23 B/W7N-u/M

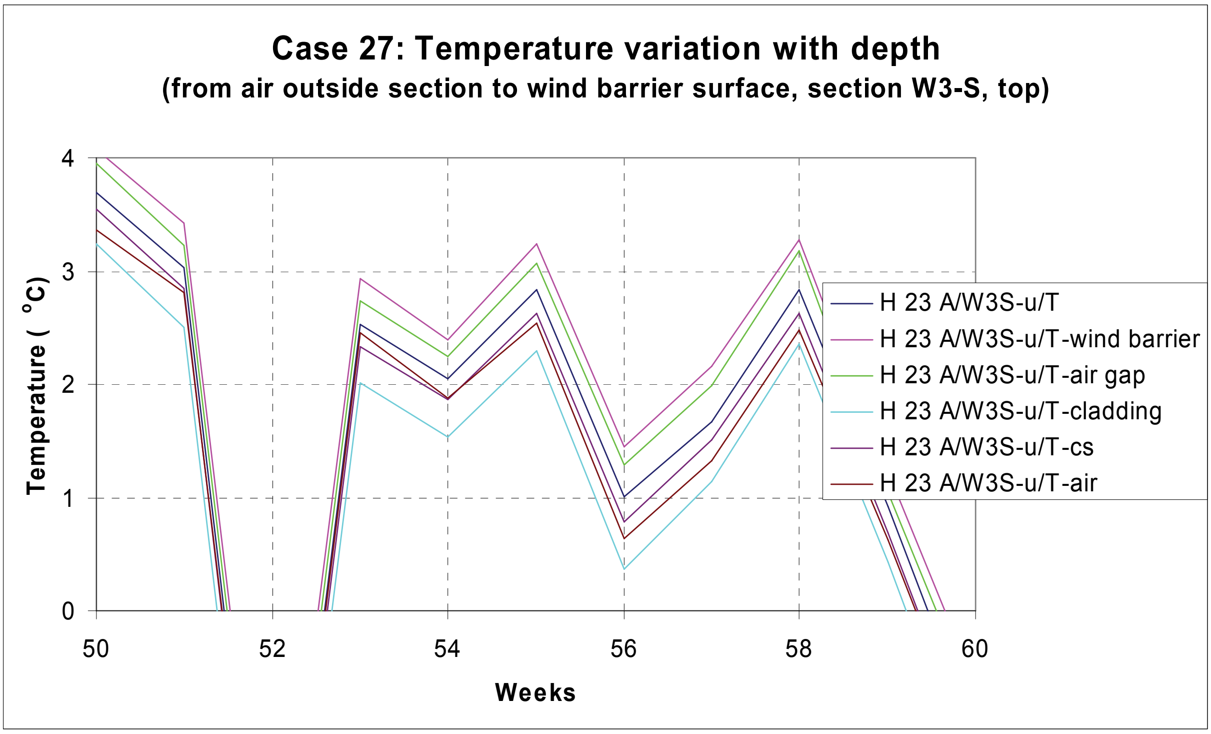

Case 24: Effect of growth rate (slow, high)
(eastern orientation, 23 mm air gap, oil based paint, top of wall)
Moisture content (weight%)
Weeks
H 23 A/E3S-u/M
S 23 A/E3N-u/M

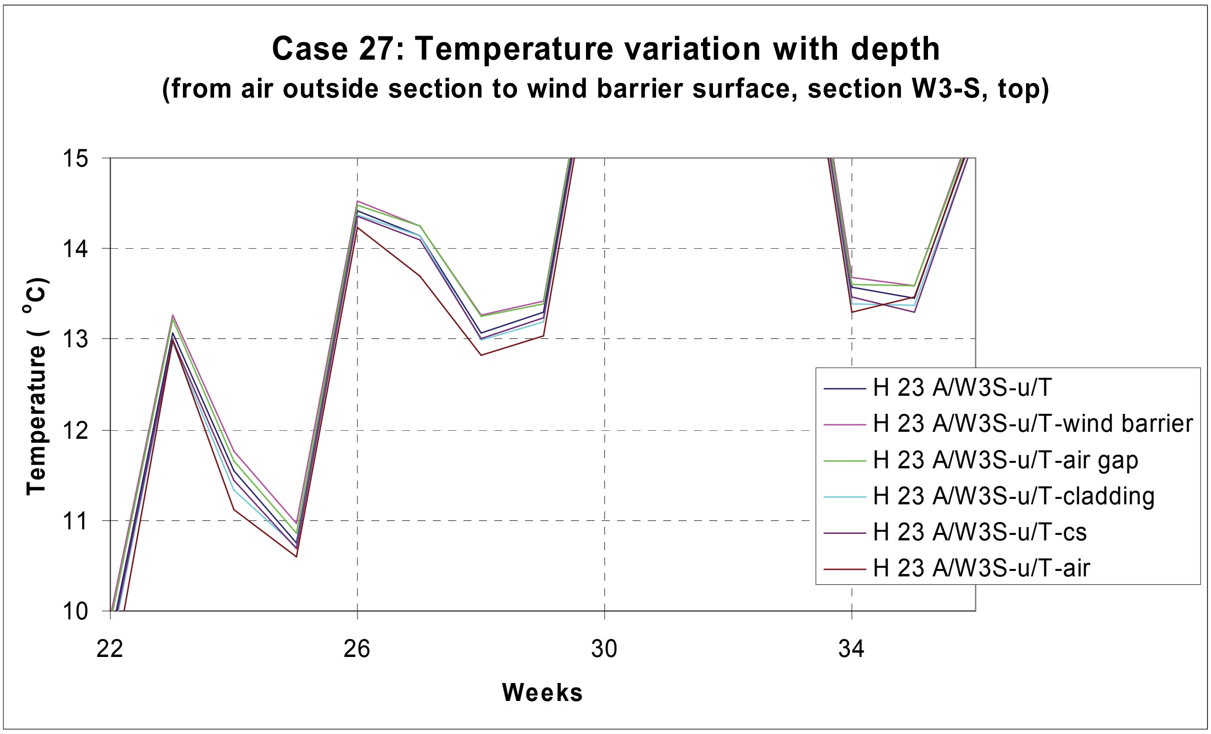

Case 25: Effect of growth rate (slow, high)
(western orientation, 4 mm air gap, untreated, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 4 Untreated/W3N-u/M
S 4 Untreated/W6S-u/M

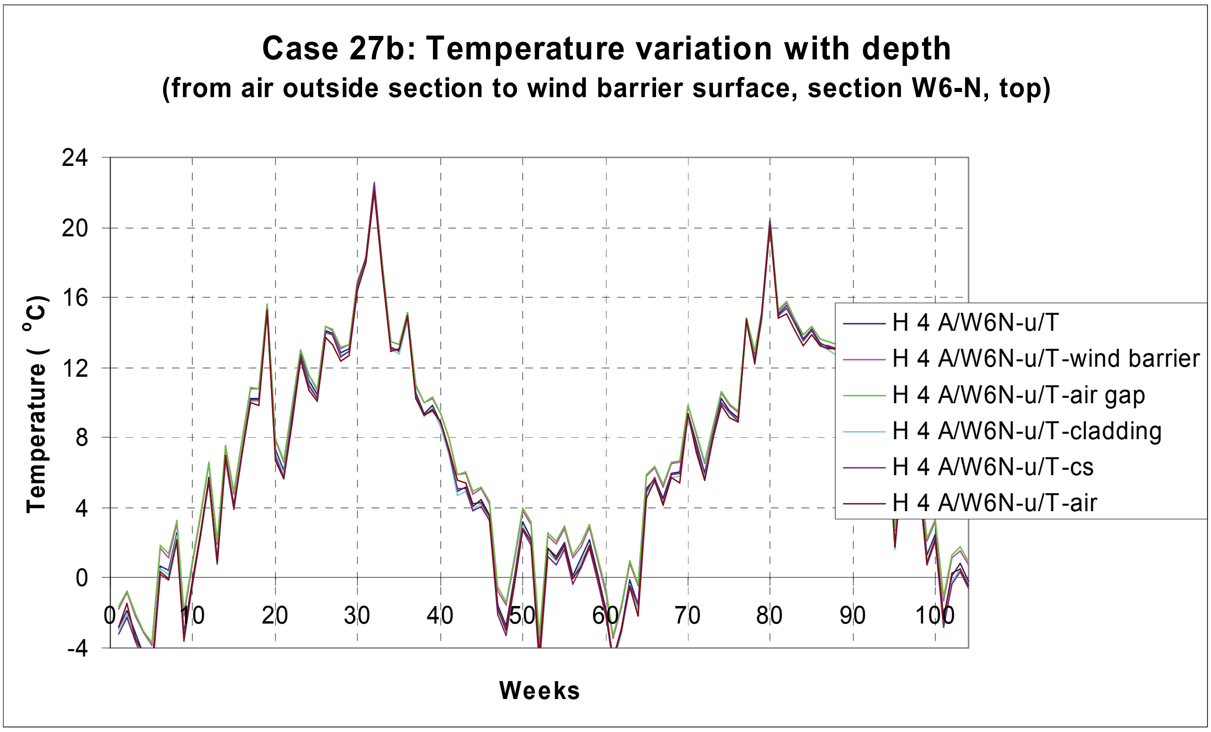

Case 26: Temperature variation with depth
(from air outside section to wind barrier surface, section W3-S, bottom)
Temperature (°C)
24
20
16
12
8
4
0
-4
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 23 A/W3S-d/T
H 23 A/W3S-d/T-wind barrier
H 23 A/W3S-d/T-air gap
H 23 A/W3S-d/T-cladding
H 23 A/W3S-d/T-cs

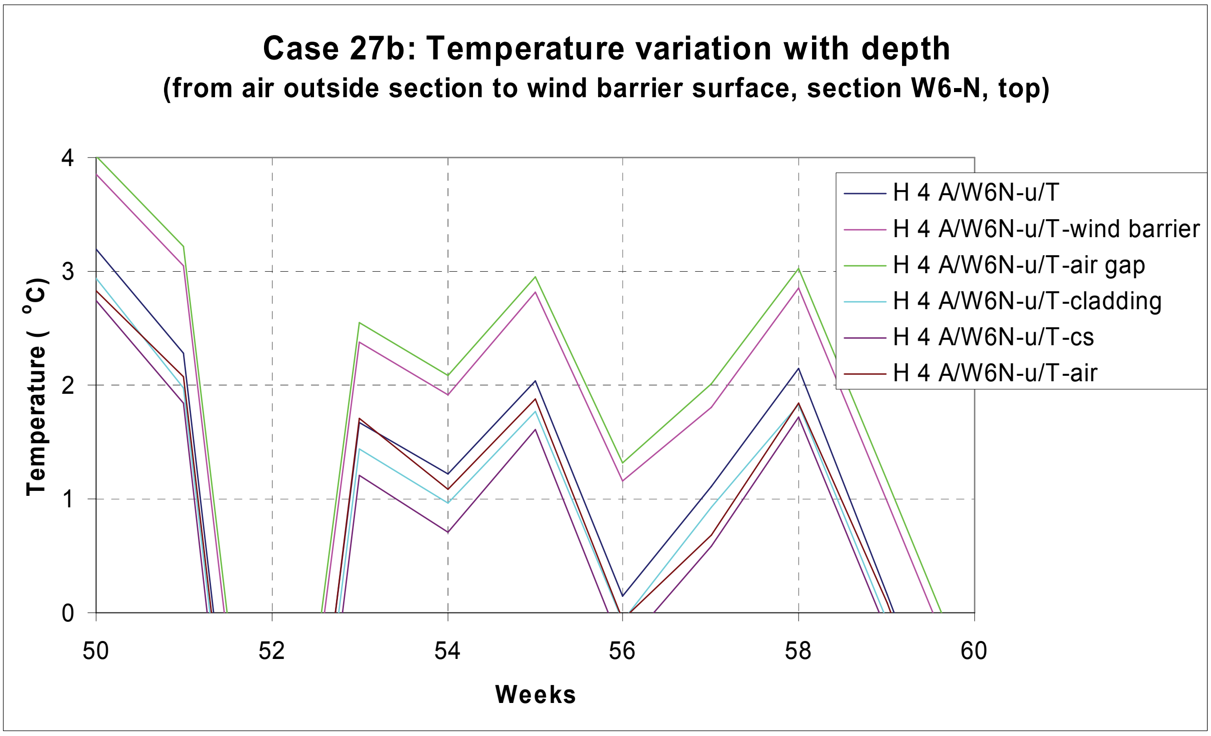

Case 26: Temperature variation with depth
(from air outside section to wind barrier surface, section W3-S, bottom)
Temperature (°C)
Weeks
H 23 A/W3S-d/T
H 23 A/W3S-d/T-wind barrier
H 23 A/W3S-d/T-air gap
H 23 A/W3S-d/T-cladding
H 23 A/W3S-d/T-cs

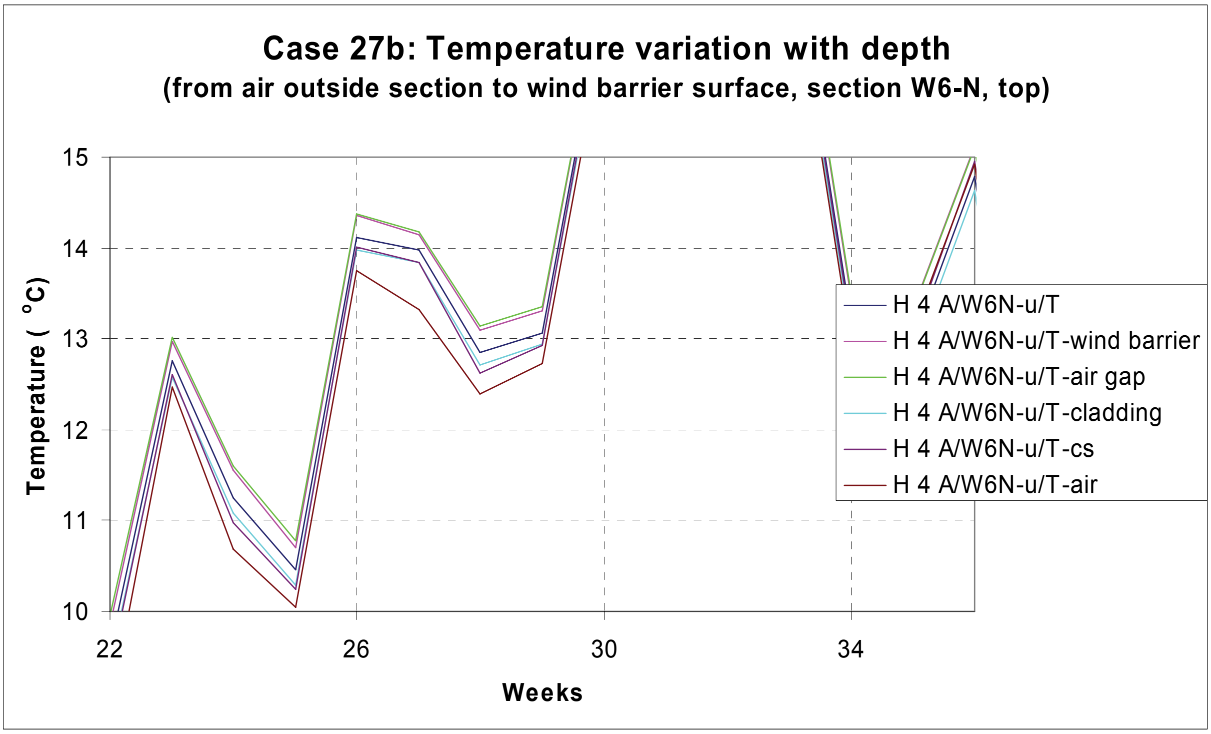

Case 27: Temperature variation with depth
(from air outside section to wind barrier surface, section W3-S, top)
Temperature (°C)
Weeks
H 23 A/W3S-u/T
H 23 A/W3S-u/T-wind barrier
H 23 A/W3S-u/T-air gap
H 23 A/W3S-u/T-cladding
H 23 A/W3S-u/T-cs
H 23 A/W3S-u/T-air

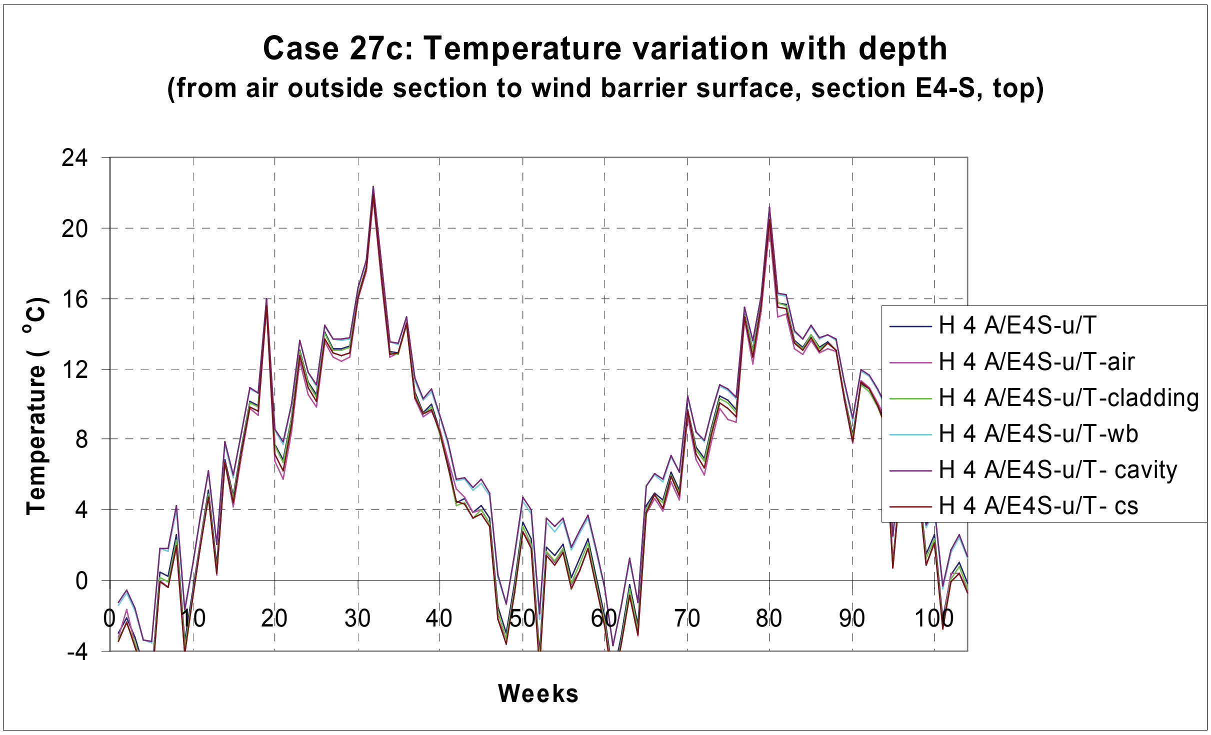

Case 27: Temperature variation with depth
(from air outside section to wind barrier surface, section W3-S, top)
Temperature (°C)
4
3
2
1
0
50
52
54
56
58
60
Weeks
H 23 A/W3S-u/T
H 23 A/W3S-u/T-wind barrier
H 23 A/W3S-u/T-air gap
H 23 A/W3S-u/T-cladding
H 23 A/W3S-u/T-cs
H 23 A/W3S-u/T-air

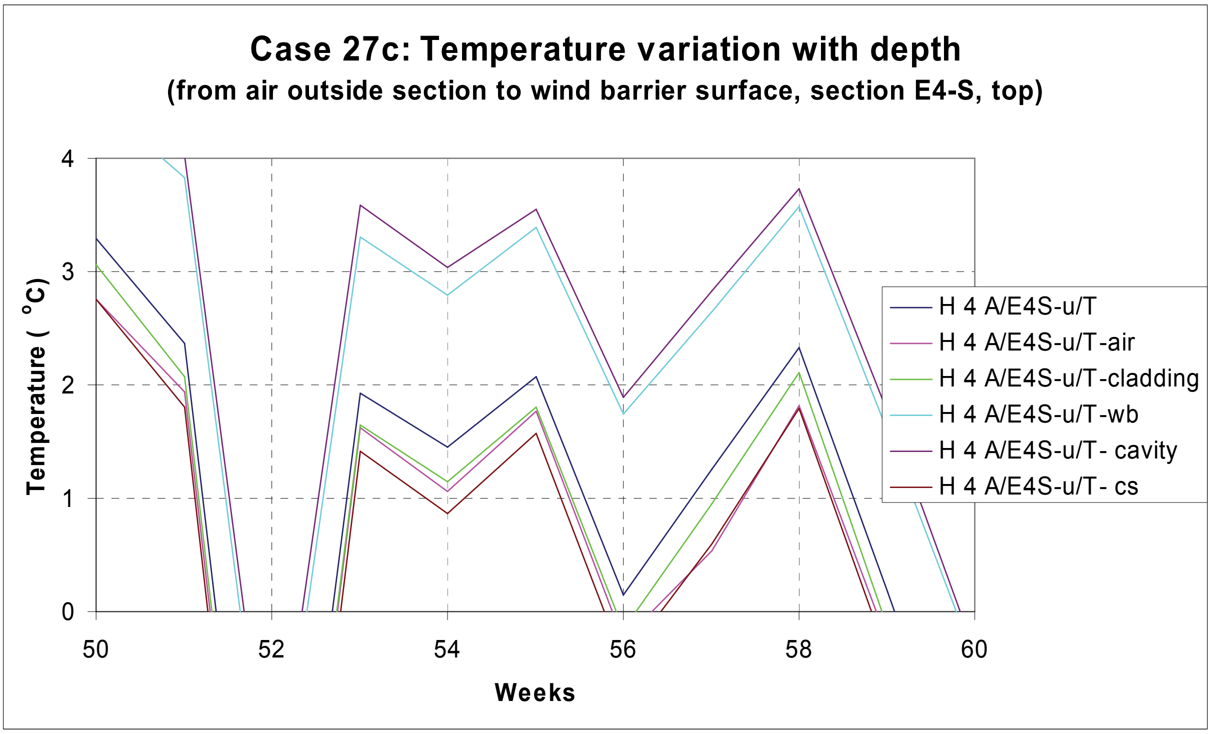

Case 27: Temperature variation with depth
(from air outside section to wind barrier surface, section W3-S, top)
Temperature (°C)
15
14
13
12
11
10
22
26
30
34
Weeks
H 23 A/W3S-u/T
H 23 A/W3S-u/T-wind barrier
H 23 A/W3S-u/T-air gap
H 23 A/W3S-u/T-cladding
H 23 A/W3S-u/T-cs
H 23 A/W3S-u/T-air

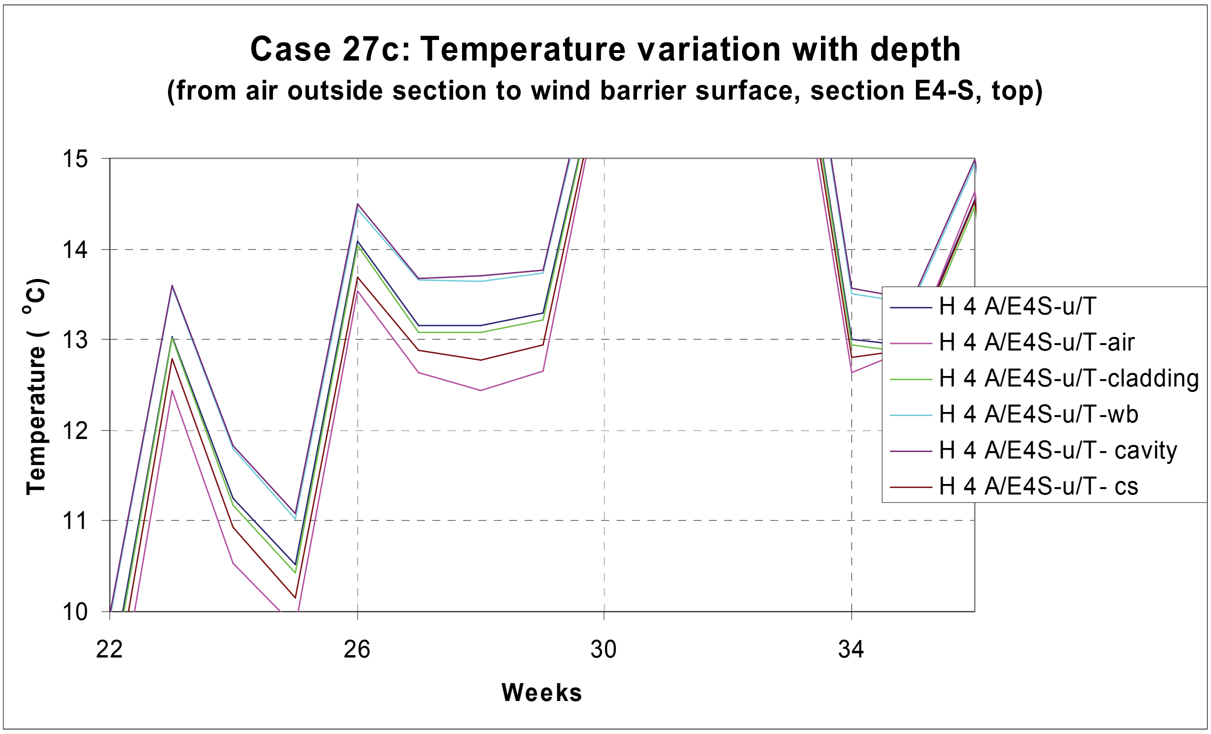

Case 27b: Temperature variation with depth
(from air outside section to wind barrier surface, section W6-N, top)
Temperature (°C)
Weeks
H 4 A/W6N-u/T
H 4 A/W6N-u/T-wind barrier
H 4 A/W6N-u/T-air gap
H 4 A/W6N-u/T-cladding
H 4 A/W6N-u/T-cs
H 4 A/W6N-u/T-air

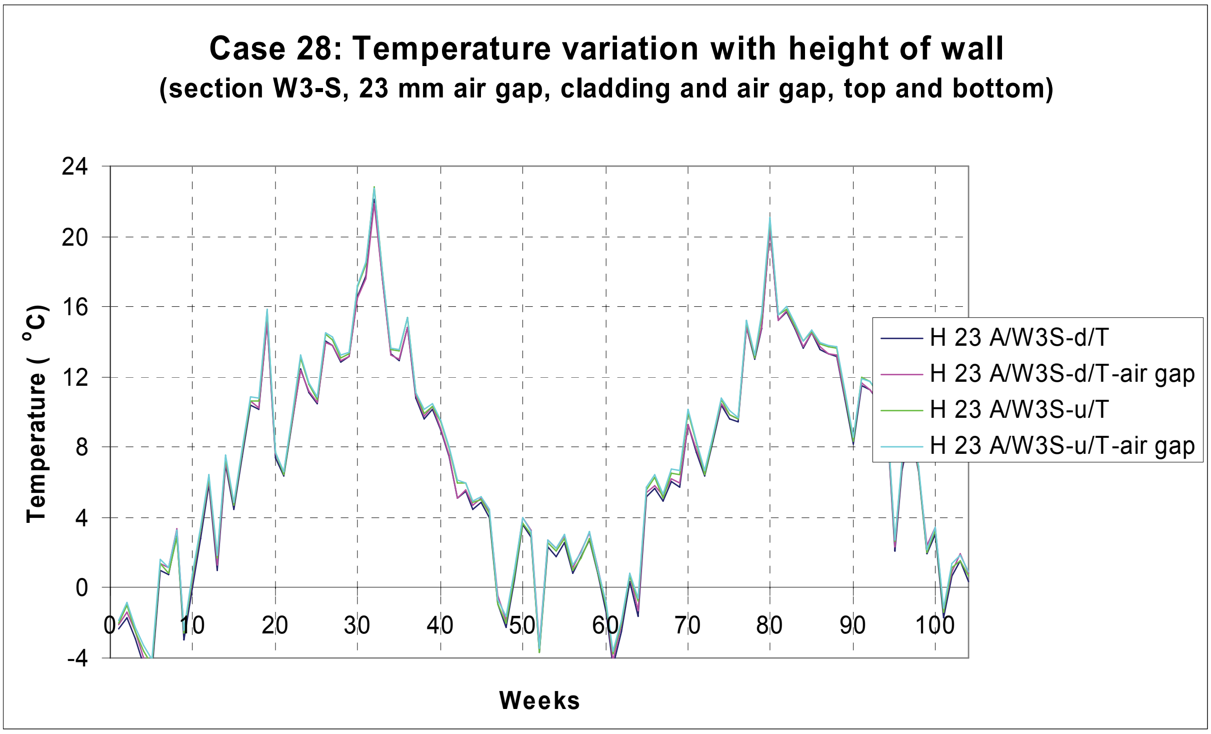

Case 27b: Temperature variation with depth
(from air outside section to wind barrier surface, section W6-N, top)
Temperature (°C)
Weeks
H 4 A/W6N-u/T
H 4 A/W6N-u/T-wind barrier
H 4 A/W6N-u/T-air gap
H 4 A/W6N-u/T-cladding
H 4 A/W6N-u/T-cs
H 4 A/W6N-u/T-air


Case 27b: Temperature variation with depth
(from air outside section to wind barrier surface, section W6-N, top)
Temperature (°C)
Weeks
15
14
13
12
11
10
22
26
30
34
H 4 A/W6N-u/T
H 4 A/W6N-u/T-wind barrier
H 4 A/W6N-u/T-air gap
H 4 A/W6N-u/T-cladding
H 4 A/W6N-u/T-cs
H 4 A/W6N-u/T-air

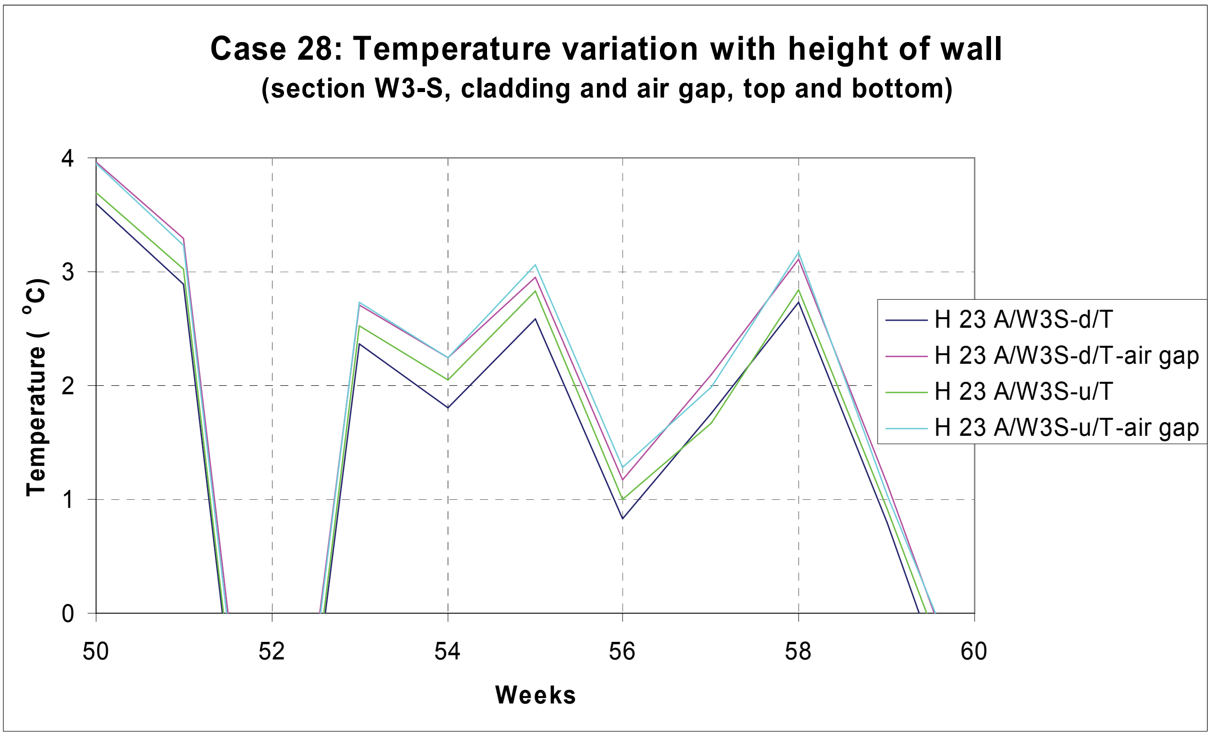

Case 27c: Temperature variation with depth
(from air outside section to wind barrier surface, section E4-S, top)
Temperature (°C)
Weeks
24
20
16
12
8
4
0
-4
0
10
20
30
40
50
60
70
80
90
100
H 4 A/E4S-u/T
H 4 A/E4S-u/T-air
H 4 A/E4S-u/T-cladding
H 4 A/E4S-u/T-wb
H 4 A/E4S-u/T- cavity
H 4 A/E4S-u/T- cs


Case 27c: Temperature variation with depth
(from air outside section to wind barrier surface, section E4-S, top)
Temperature (°C)
Weeks
0
1
2
3
4
50
52
54
56
58
60
H 4 A/E4S-u/T
H 4 A/E4S-u/T-air
H 4 A/E4S-u/T-cladding
H 4 A/E4S-u/T-wb
H 4 A/E4S-u/T- cavity
H 4 A/E4S-u/T- cs

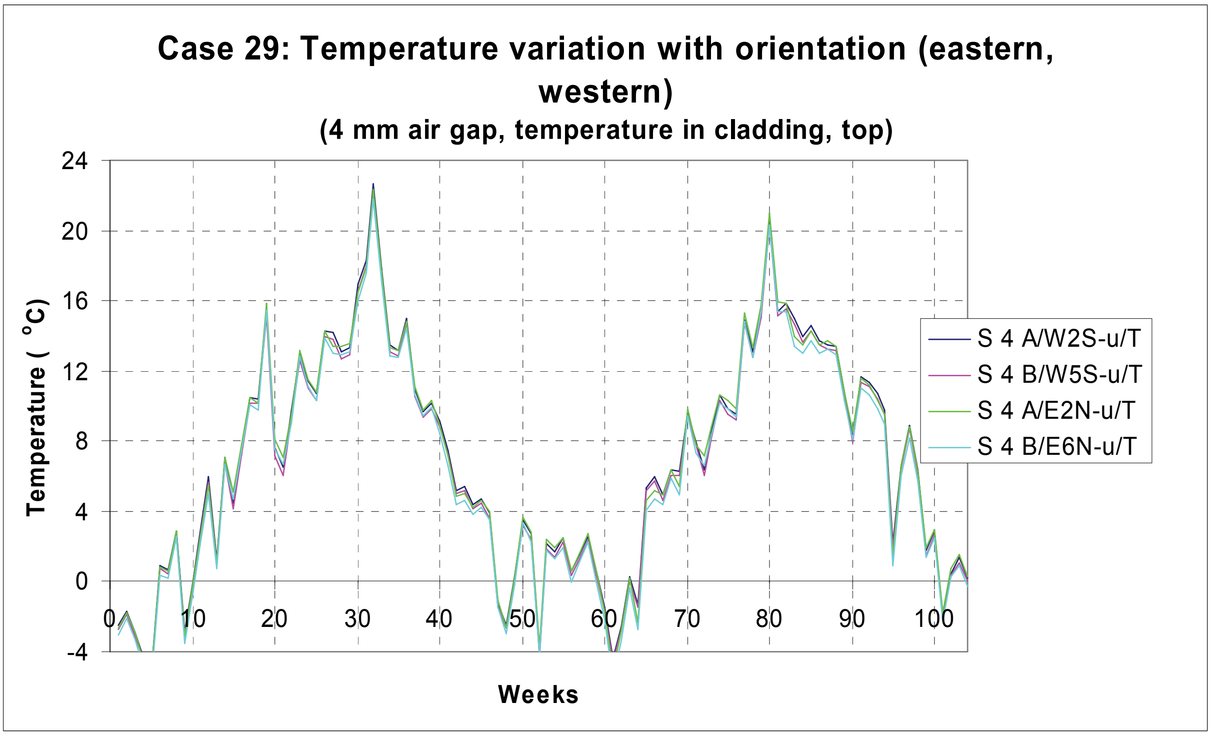

Case 27c: Temperature variation with depth
(from air outside section to wind barrier surface, section E4-S, top)
Temperature (°C)
Weeks
10
11
12
13
14
15
22
26
30
34
H 4 A/E4S-u/T
H 4 A/E4S-u/T-air
H 4 A/E4S-u/T-cladding
H 4 A/E4S-u/T-wb
H 4 A/E4S-u/T- cavity
H 4 A/E4S-u/T- cs

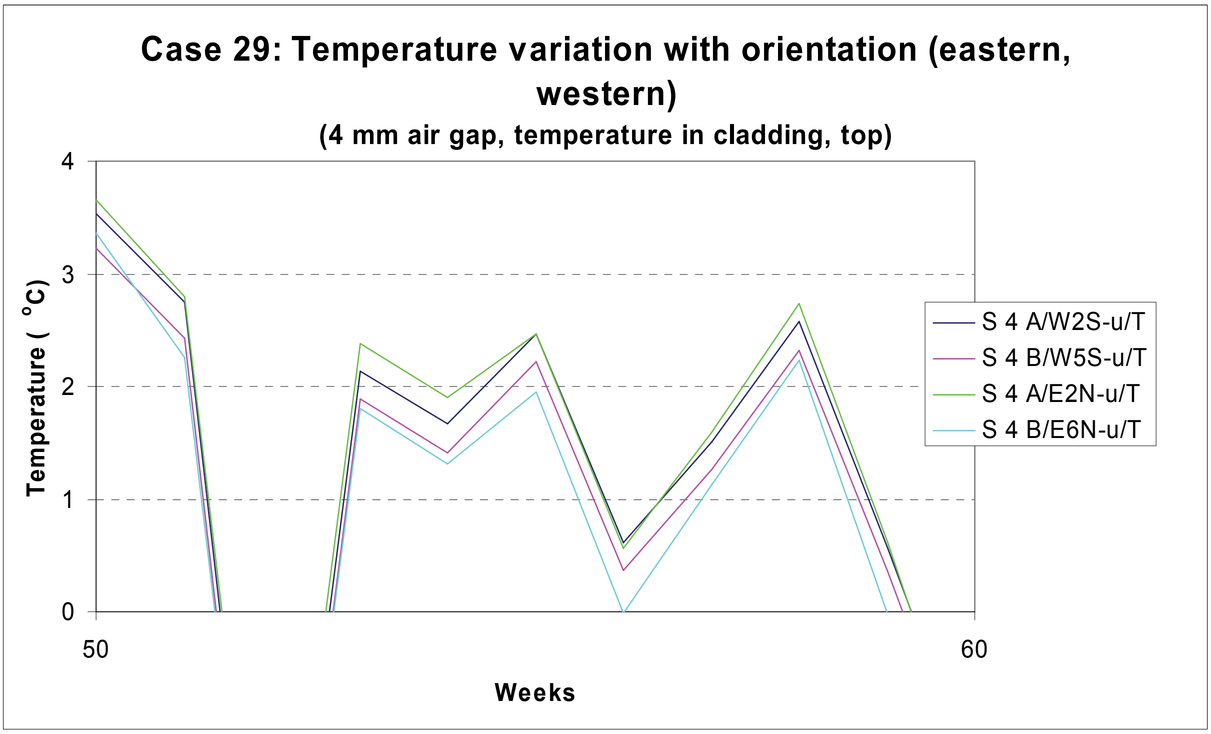


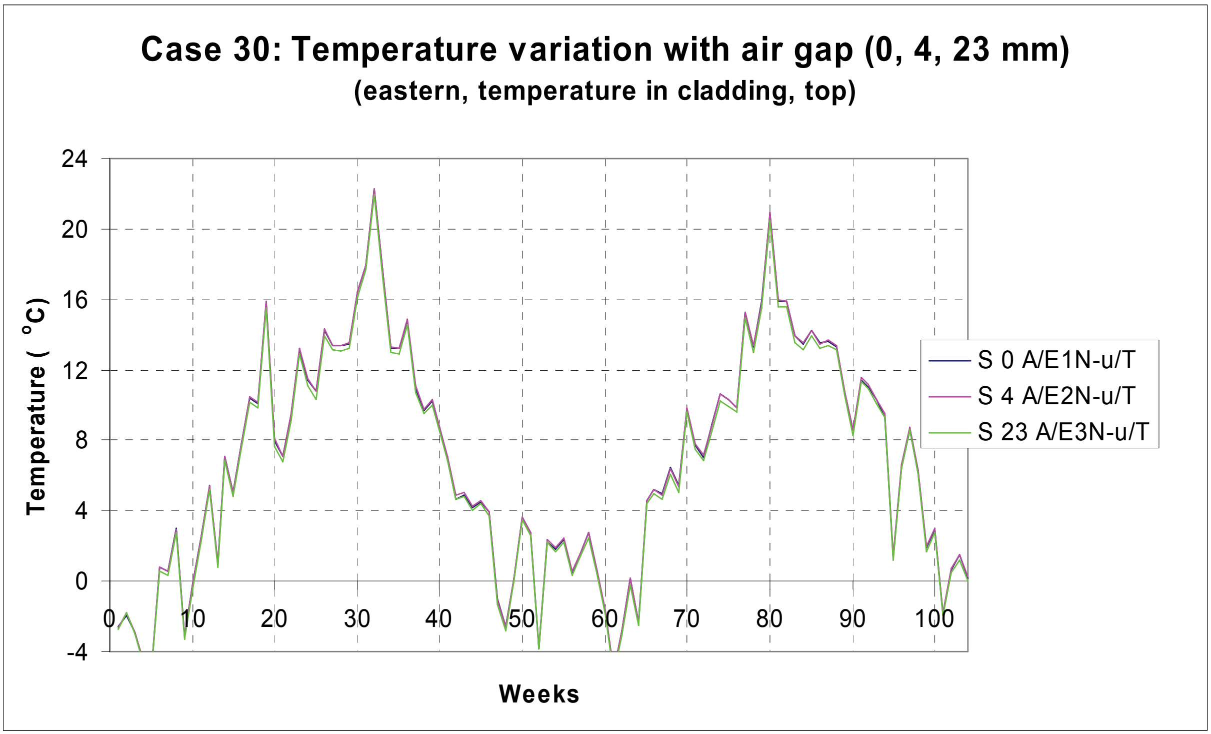
Case 28: Temperature variation with height of wall
(section W3-S, 23 mm air gap, cladding and air gap, top and bottom)
24
20
16
12
8
4
0
-4
Temperature (°C)
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 23 A/W3S-d/T
H 23 A/W3S-d/T-air gap
H 23 A/W3S-u/T
H 23 A/W3S-u/T-air gap

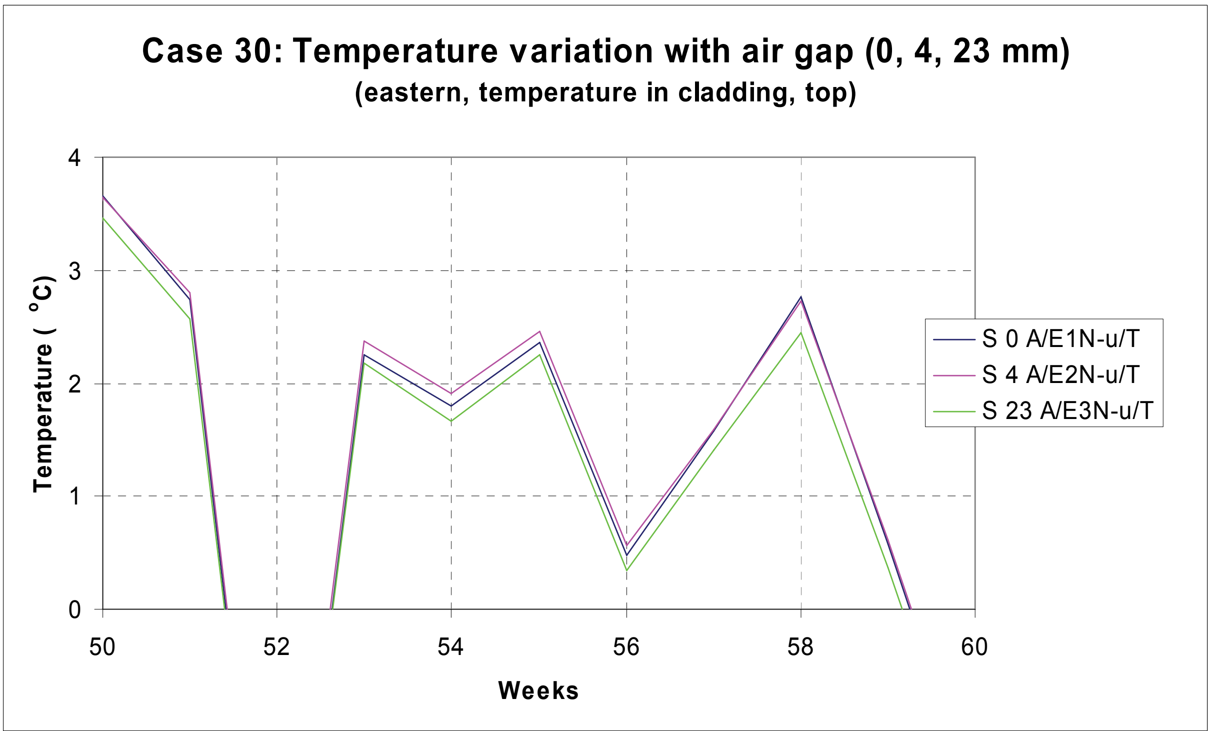


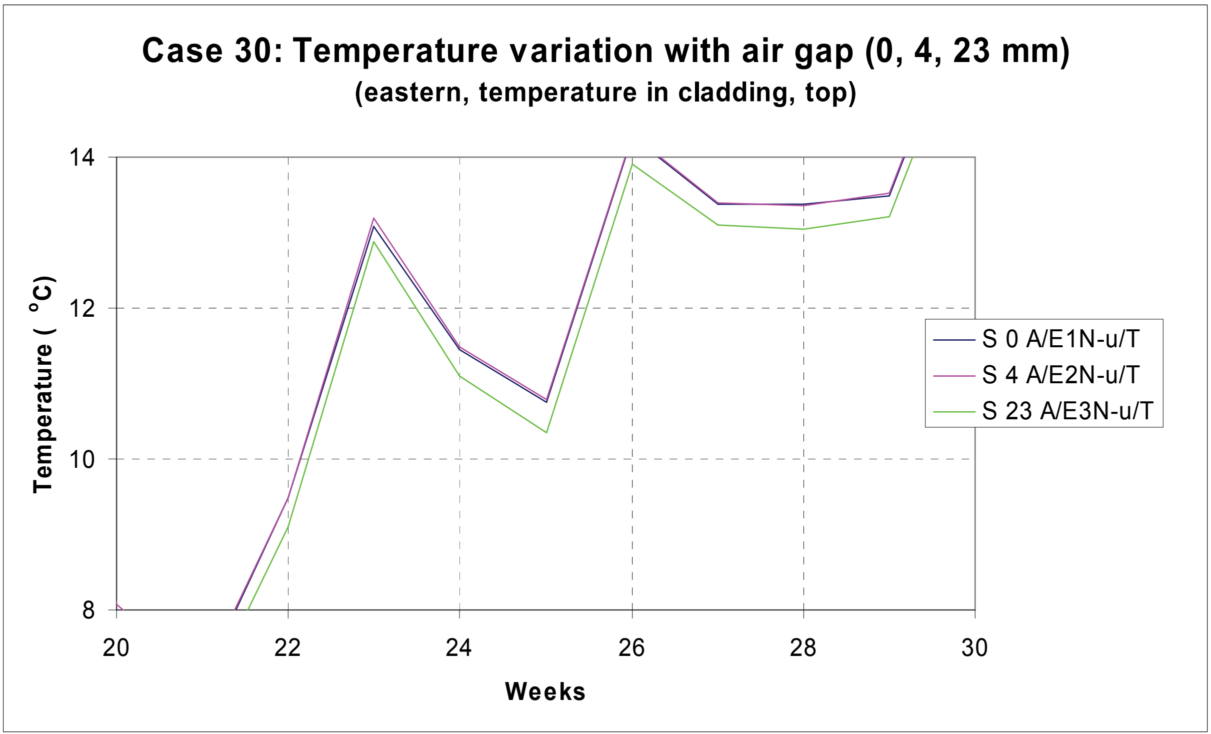
Case 28: Temperature variation with height of wall
(section W3-S, cladding and air gap, top and bottom)
4
3
2
1
0
Temperature (°C)
50
52
54
56
58
60
Weeks
H 23 A/W3S-d/T
H 23 A/W3S-d/T-air gap
H 23 A/W3S-u/T
H 23 A/W3S-u/T-air gap

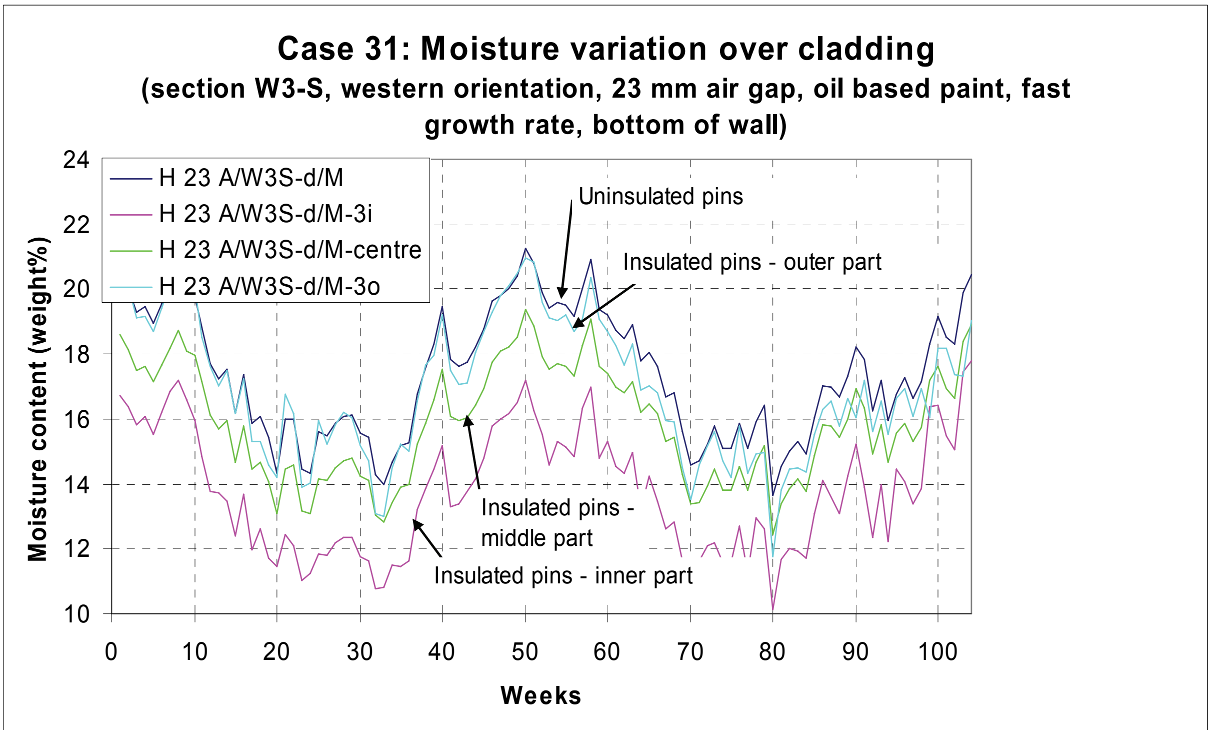

Case 29: Temperature variation with orientation (eastern, western)
(4 mm air gap, temperature in cladding, top)
Temperature (°C)
Weeks
24
20
16
12
8
4
0
-4
0
10
20
30
40
50
60
70
80
90
100
S 4 A/W2S-u/T
S 4 B/W5S-u/T
S 4 A/E2N-u/T
S 4 B/E6N-u/T

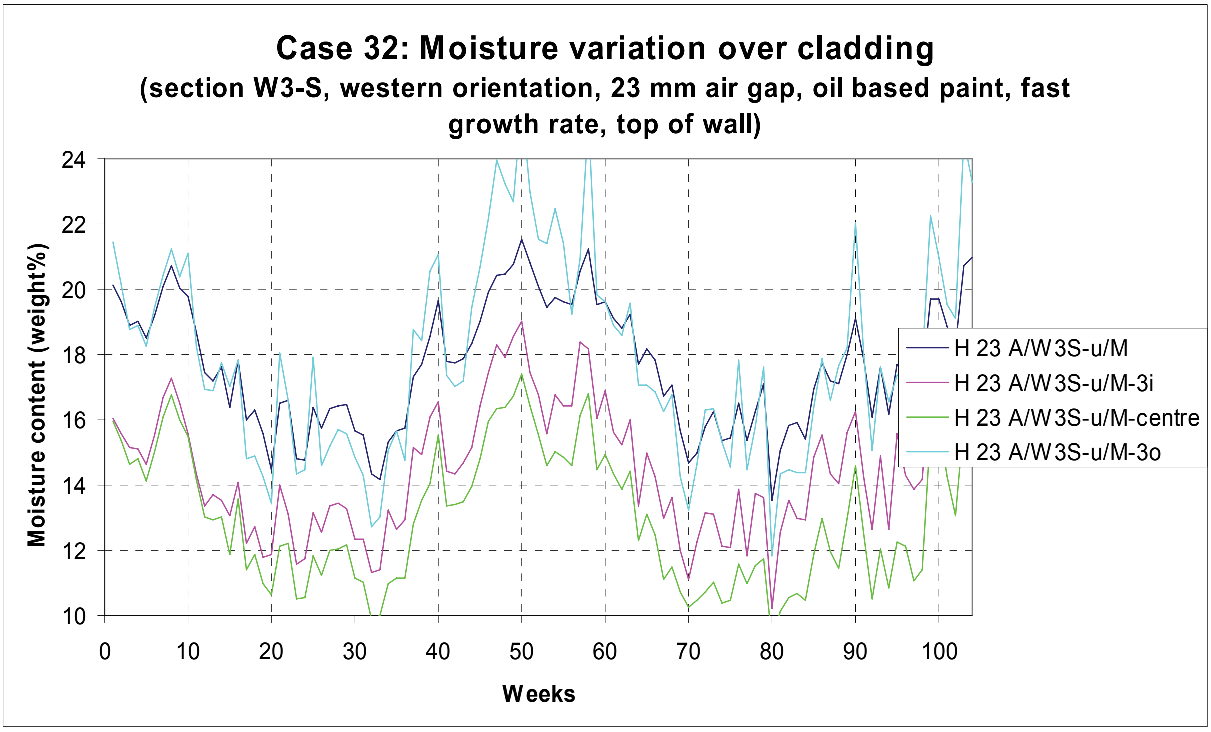

Case 29: Temperature variation with orientation (eastern, western)
(4 mm air gap, temperature in cladding, top)
Temperature (°C)
Weeks
4
3
2
1
0
50
60
S 4 A/W2S-u/T
S 4 B/W5S-u/T
S 4 A/E2N-u/T
S 4 B/E6N-u/T

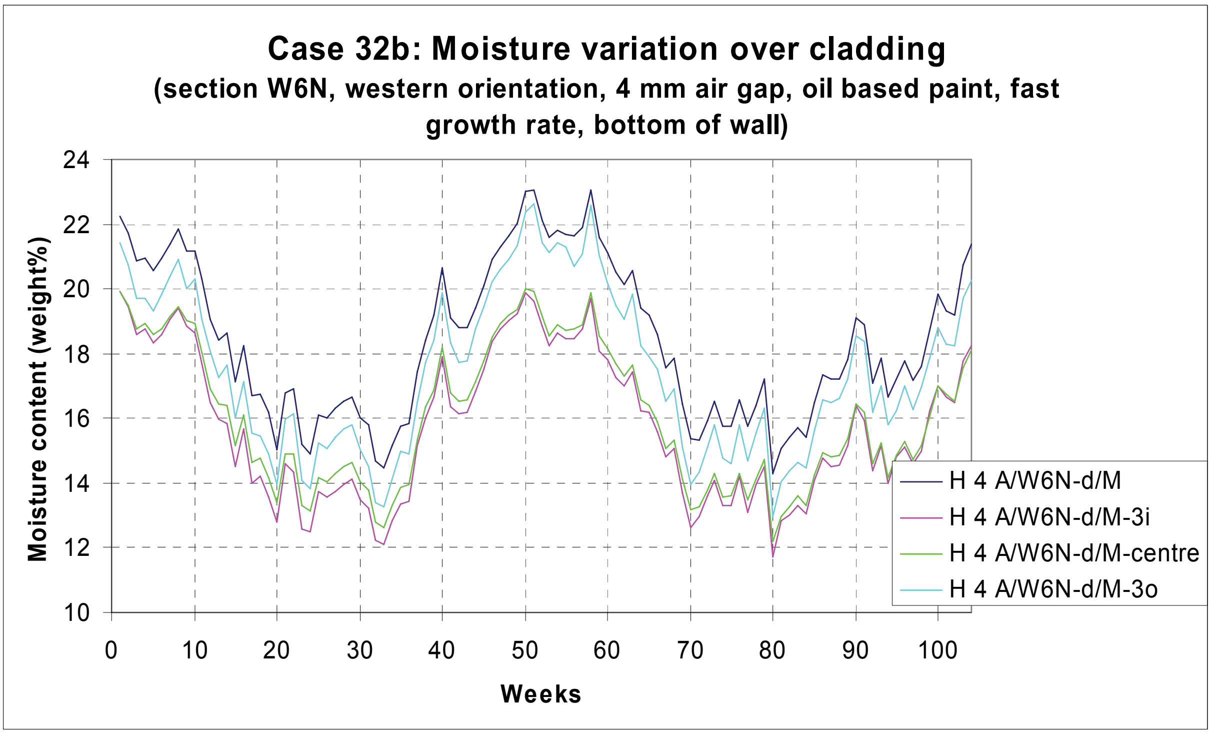

Case 30: Temperature variation with air gap (0, 4, 23 mm)
(eastern, temperature in cladding, top)
Temperature (°C)
Weeks
S 0 A/E1N-u/T
S 4 A/E2N-u/T
S 23 A/E3N-u/T
24
20
16
12
8
4
0
-4
0
10
20
30
40
50
60
70
80
90
100

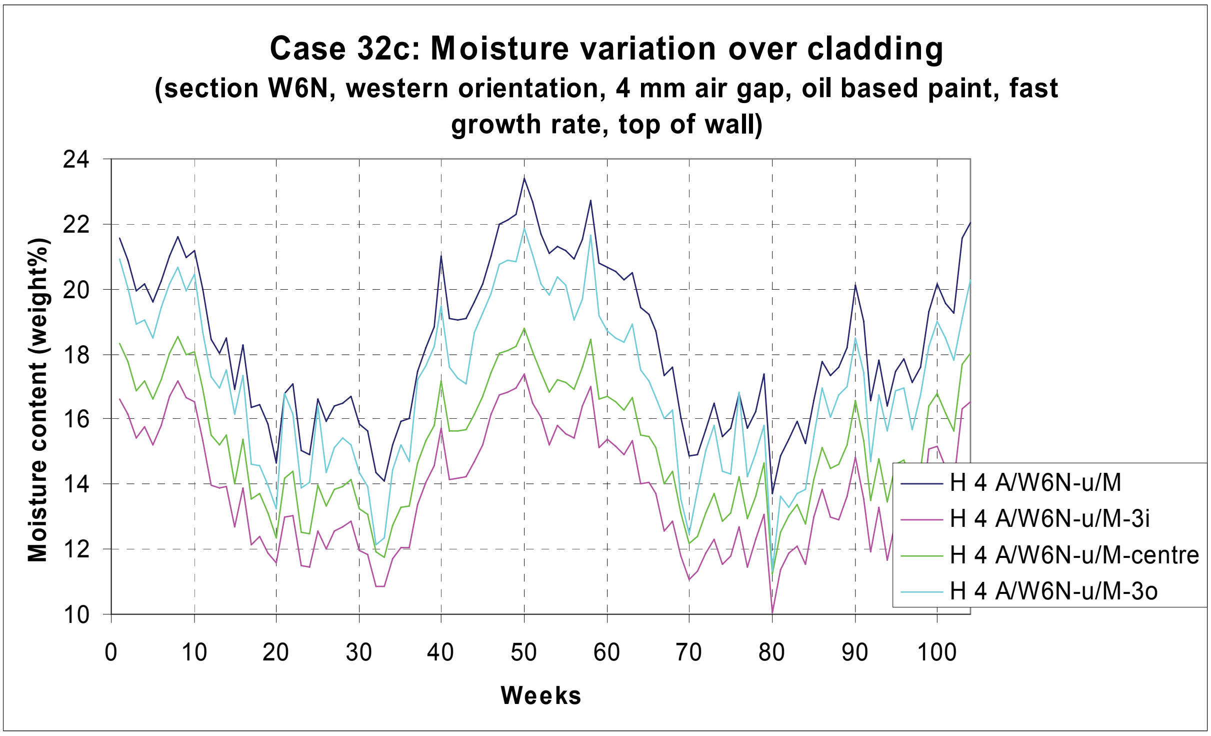

Case 30: Temperature variation with air gap (0, 4, 23 mm)
(eastern, temperature in cladding, top)
Temperature (°C)
Weeks
S 0 A/E1N-u/T
S 4 A/E2N-u/T
S 23 A/E3N-u/T
4
3
2
1
0
50
52
54
56
58
60

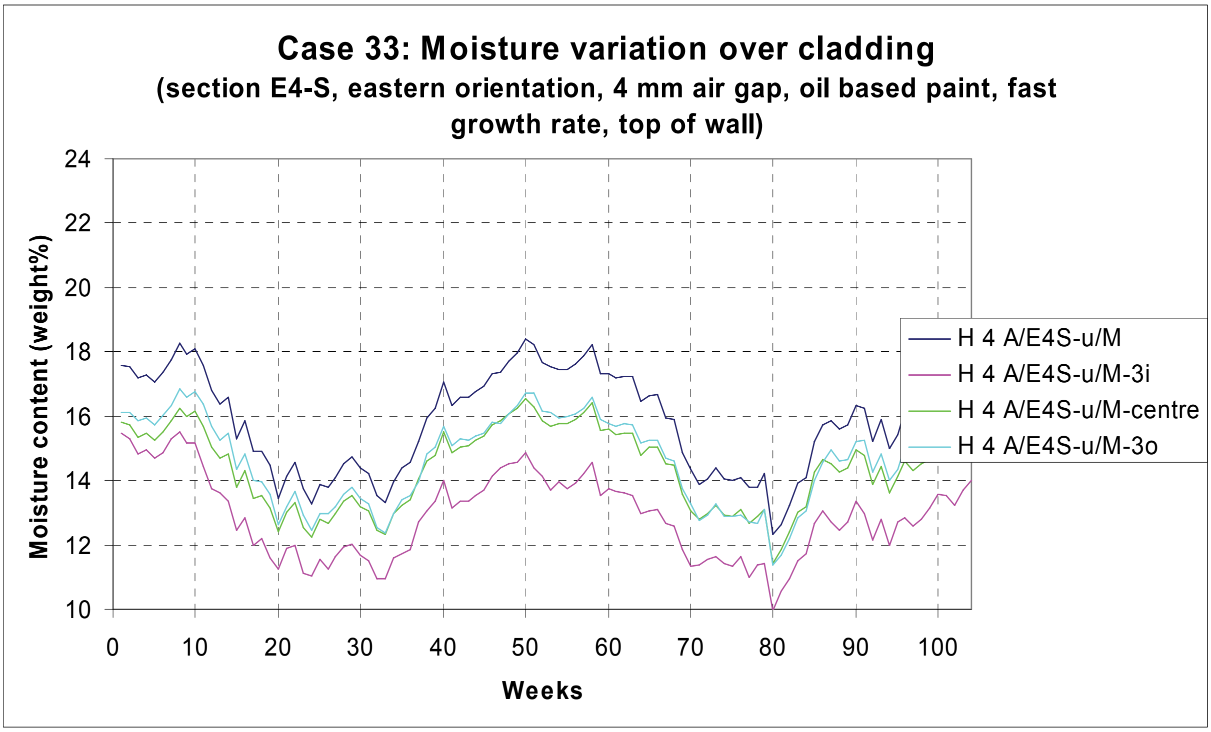

Case 30: Temperature variation with air gap (0, 4, 23 mm)
(eastern, temperature in cladding, top)
Temperature (°C)
14
12
10
8
20
22
24
26
28
30
Weeks
S 0 A/E1N-u/T
S 4 A/E2N-u/T
S 23 A/E3N-u/T

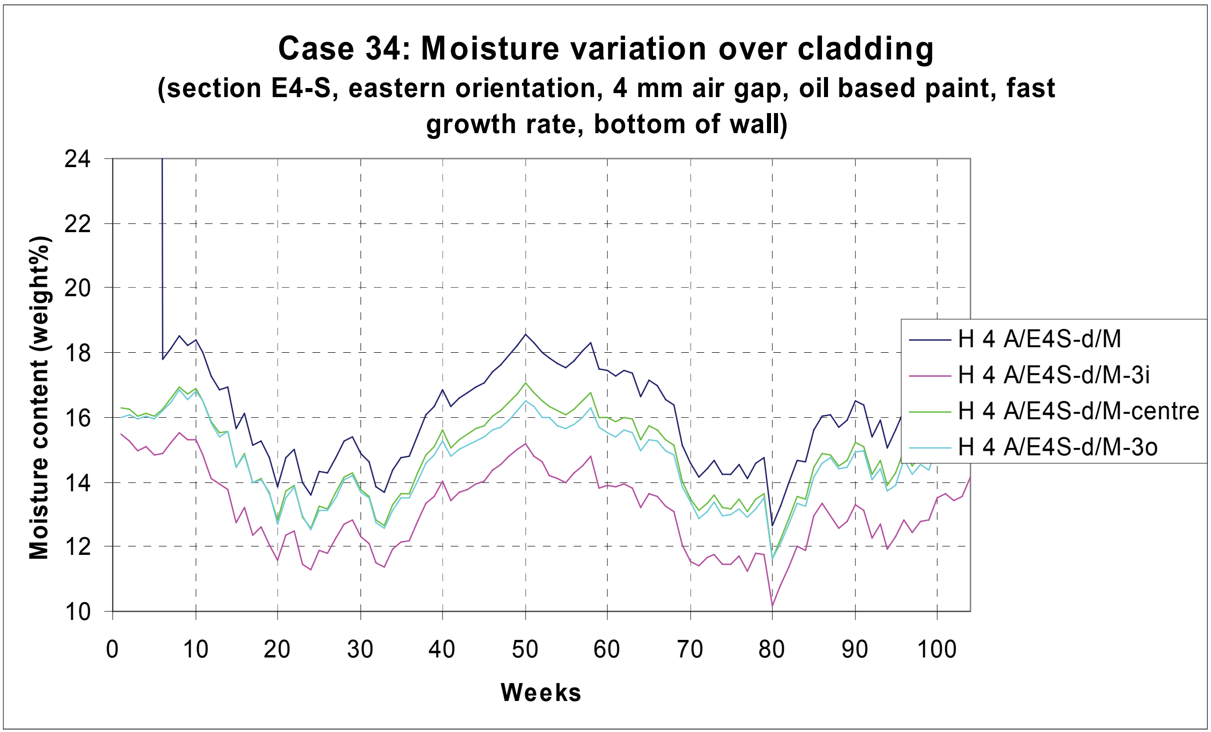

Case 31: Moisture variation over cladding
(section W3-S, western orientation, 23 mm air gap, oil based paint, fast growth rate, bottom of wall)
Moisture content (weight%)
24
22
20
18
16
14
12
10
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 23 A/W3S-d/M
H 23 A/W3S-d/M-3i
H 23 A/W3S-d/M-centre
H 23 A/W3S-d/M-3o
Uninsulated pins
Insulated pins - outer part
Insulated pins - middle part
Insulated pins - inner part

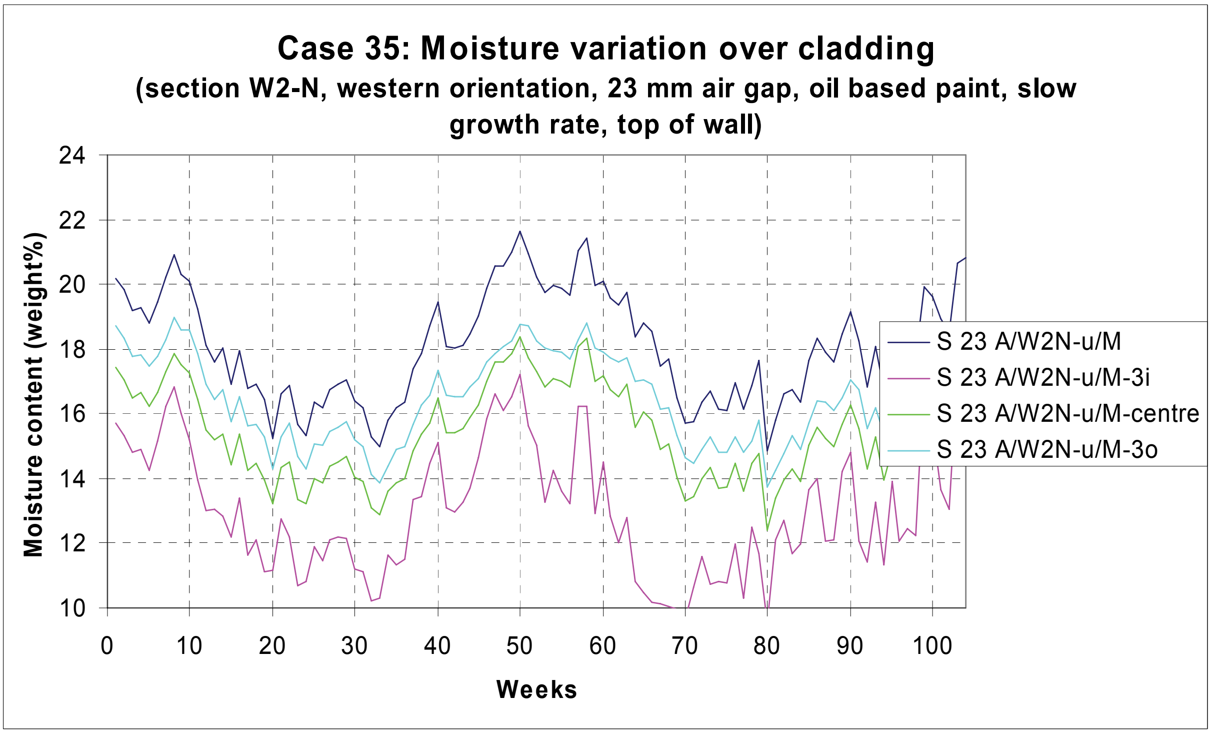

Case 32: Moisture variation over cladding
(section W3-S, western orientation, 23 mm air gap, oil based paint, fast growth rate, top of wall)
Moisture content (weight%)
Weeks
H 23 A/W3S-u/M
H 23 A/W3S-u/M-3i
H 23 A/W3S-u/M-centre
H 23 A/W3S-u/M-3o

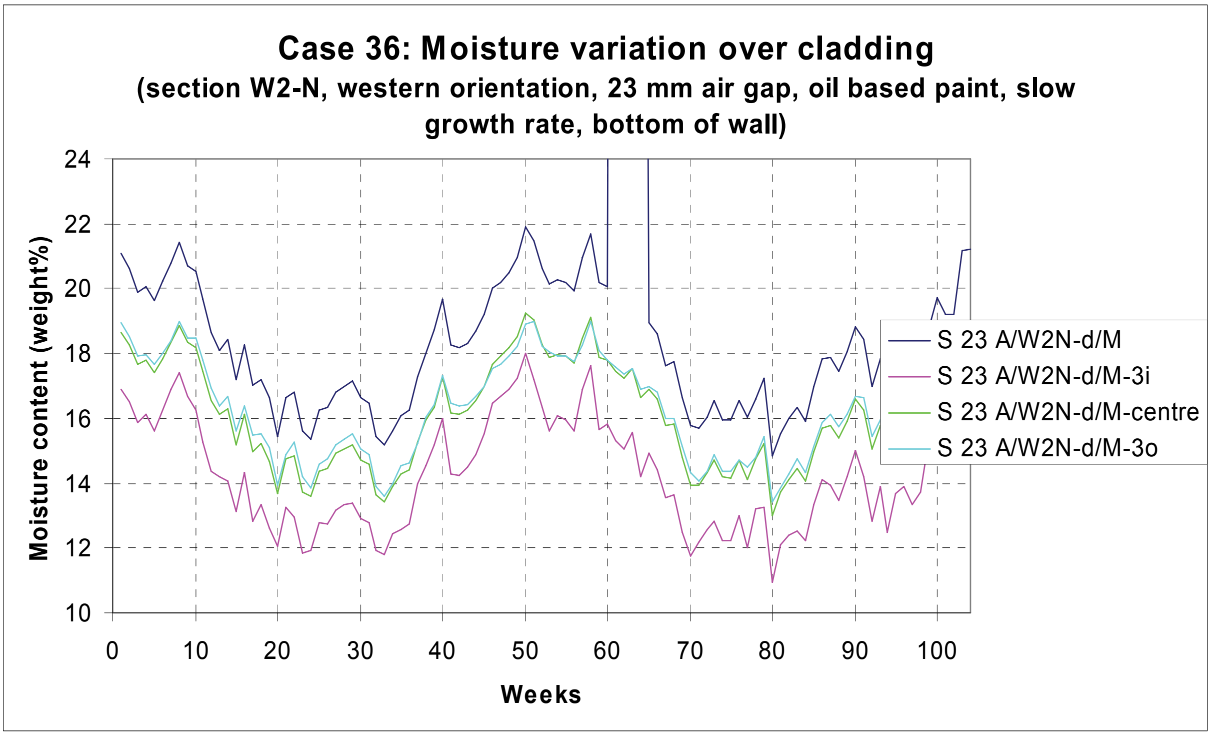

Case 32b: Moisture variation over cladding
(section W6N, western orientation, 4 mm air gap, oil based paint, fast growth rate, bottom of wall)
Moisture content (weight%)
Weeks
H 4 A/W6N-d/M
H 4 A/W6N-d/M-3i
H 4 A/W6N-d/M-centre
H 4 A/W6N-d/M-3o

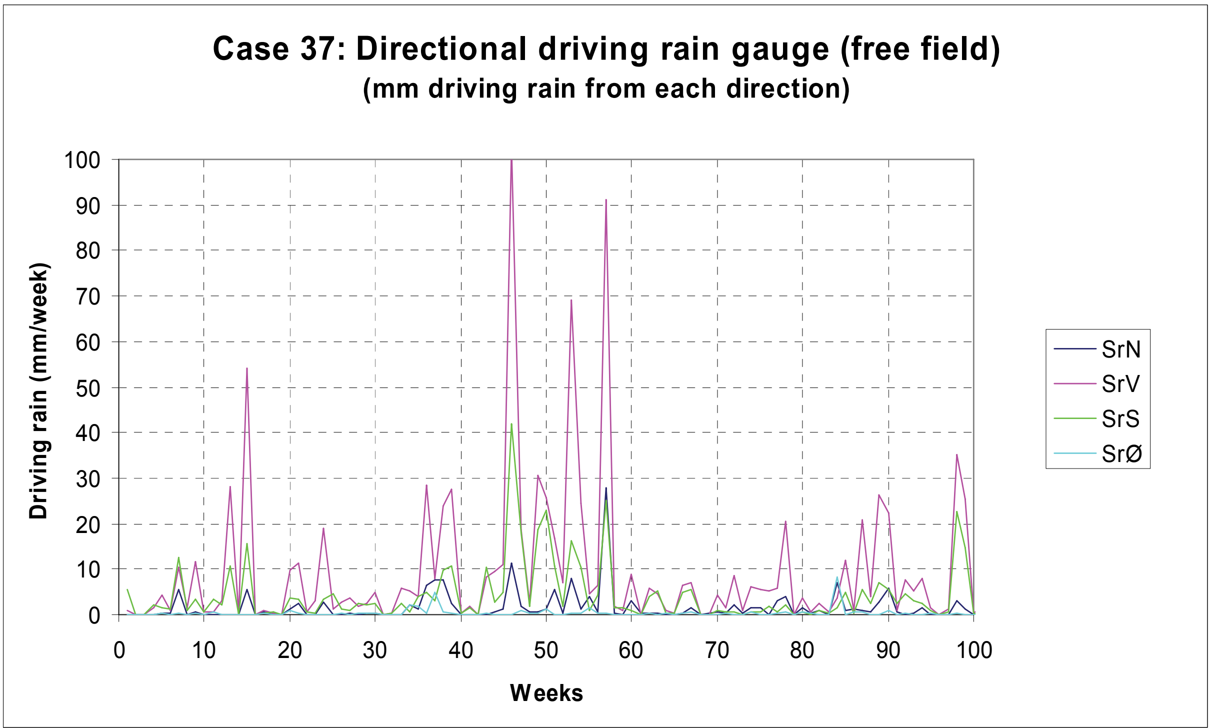

Case 32c: Moisture variation over cladding
(section W6N, western orientation, 4 mm air gap, oil based paint, fast growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
12
10
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 4 A/W6N-u/M
H 4 A/W6N-u/M-3i
H 4 A/W6N-u/M-centre
H 4 A/W6N-u/M-3o

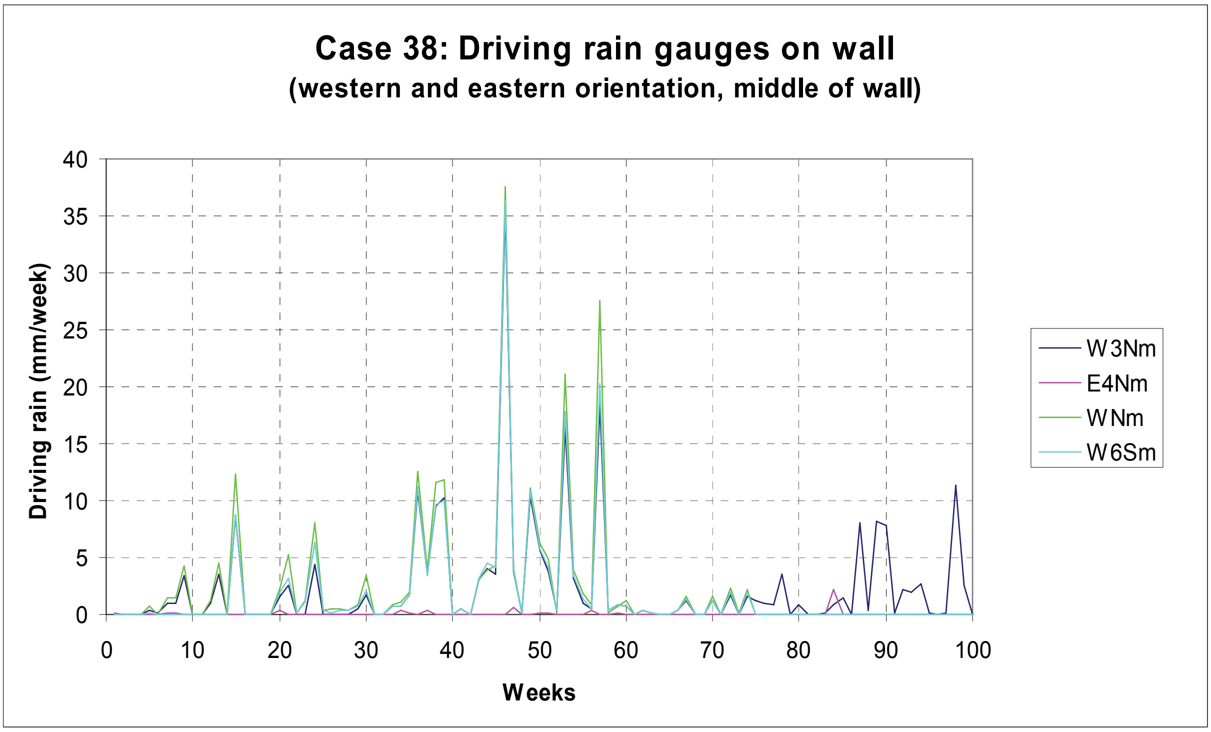

Case 33: Moisture variation over cladding
(section E4-S, eastern orientation, 4 mm air gap, oil based paint, fast growth rate, top of wall)
Moisture content (weight%)
24
22
20
18
16
14
12
10
0
10
20
30
40
50
60
70
80
90
100
Weeks
H 4 A/E4S-u/M
H 4 A/E4S-u/M-3i
H 4 A/E4S-u/M-centre
H 4 A/E4S-u/M-3o

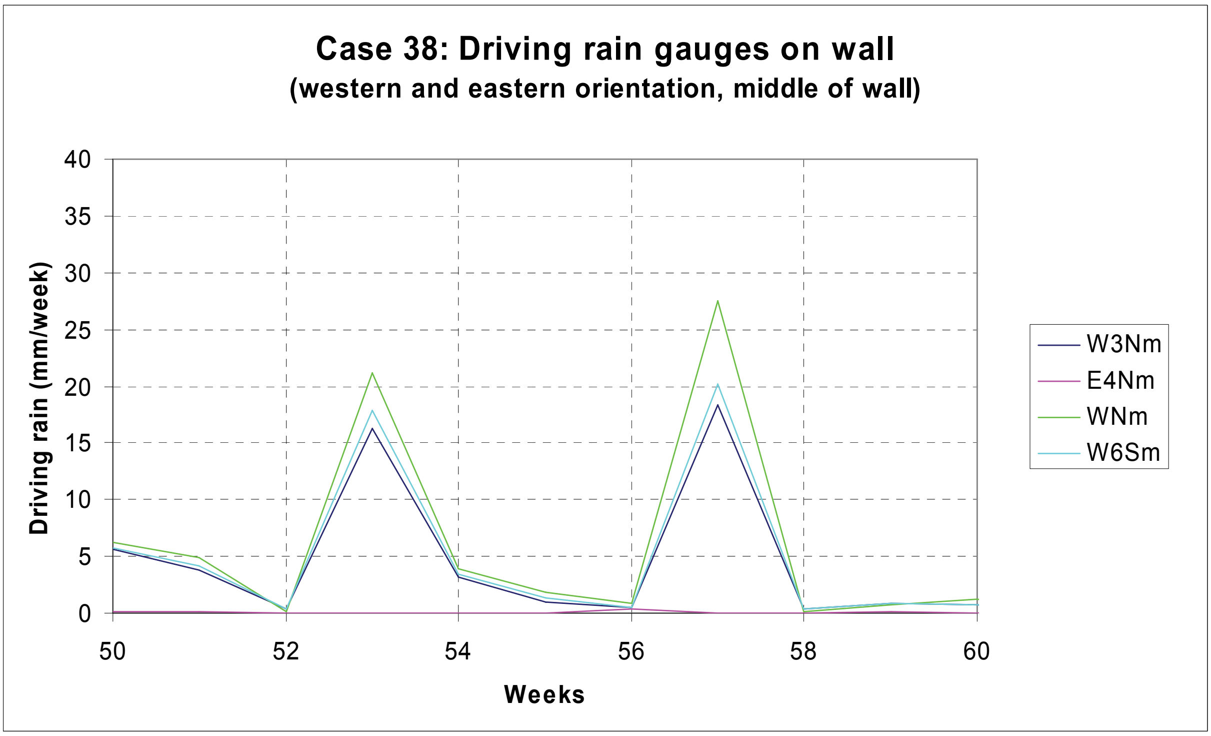

Case 34: Moisture variation over cladding
(section E4-S, eastern orientation, 4 mm air gap, oil based paint, fast growth rate, bottom of wall)
Moisture content (weight%)
Weeks
H 4 A/E4S-d/M
H 4 A/E4S-d/M-3i
H 4 A/E4S-d/M-centre
H 4 A/E4S-d/M-3o

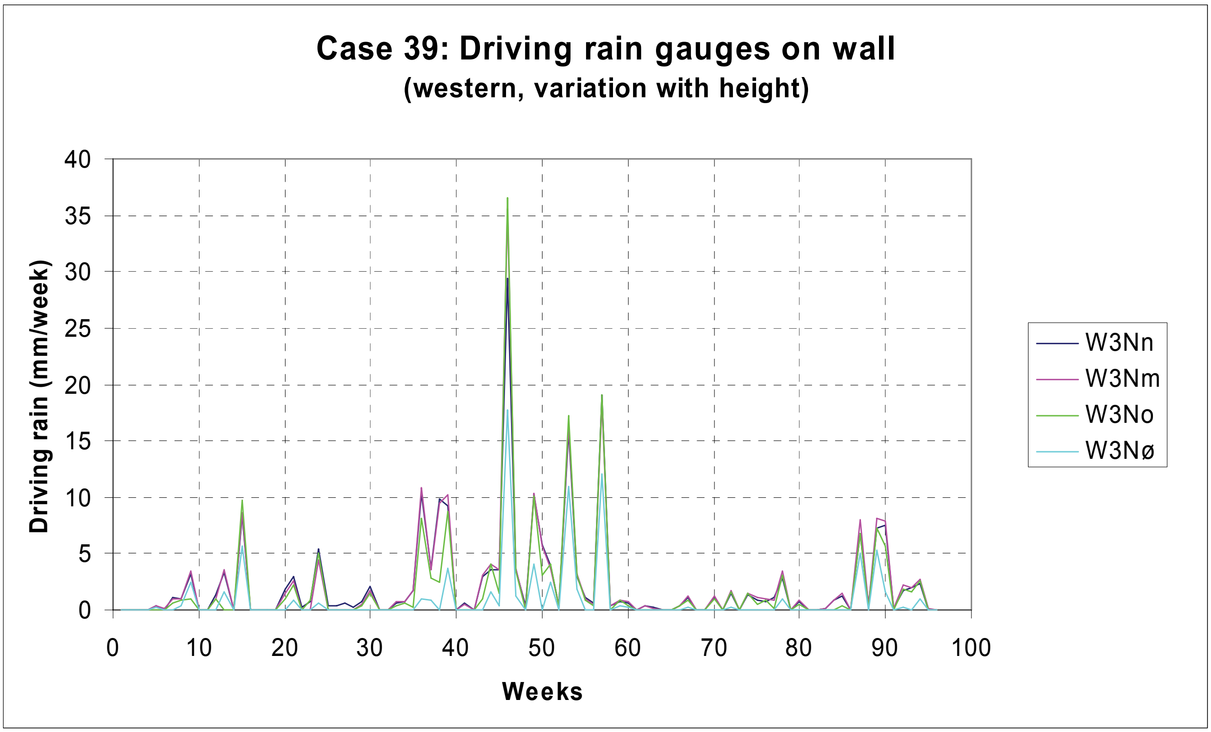

Case 35: Moisture variation over cladding
(section W2-N, western orientation, 23 mm air gap, oil based paint, slow growth rate, top of wall)
Moisture content (weight%)
Weeks
S 23 A/W2N-u/M
S 23 A/W2N-u/M-3i
S 23 A/W2N-u/M-centre
S 23 A/W2N-u/M-3o

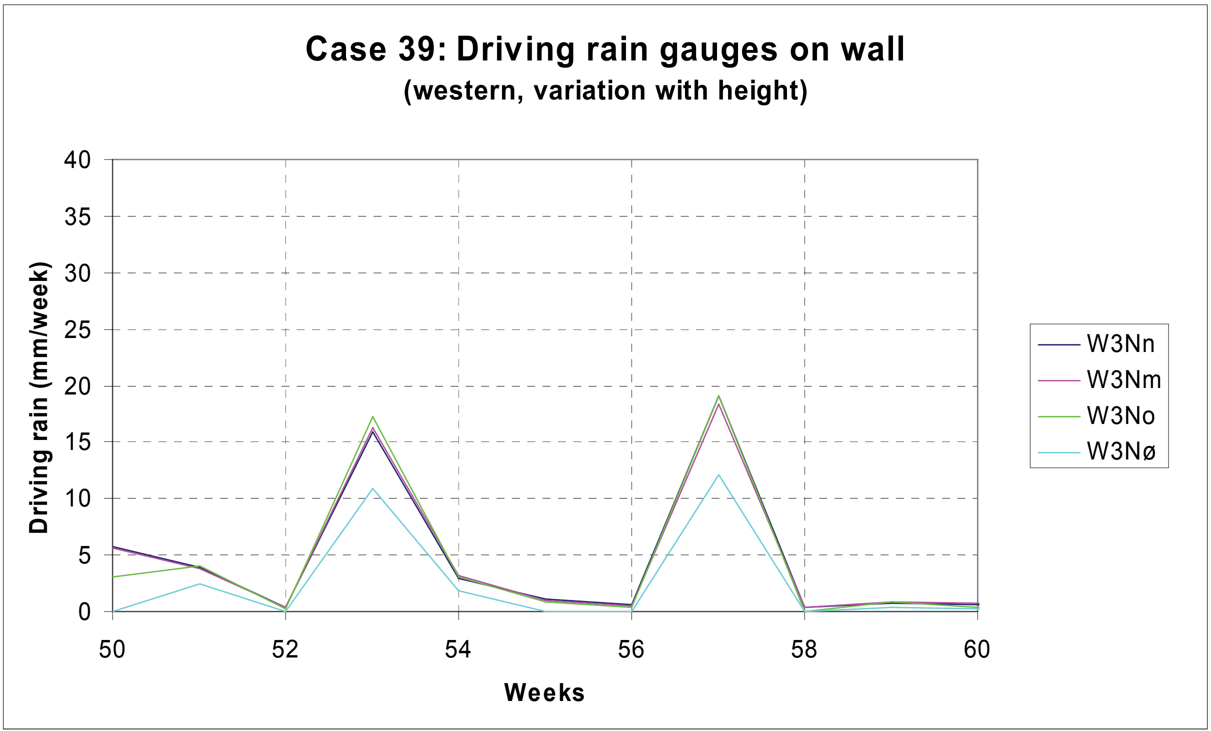

Case 36: Moisture variation over cladding
(section W2-N, western orientation, 23 mm air gap, oil based paint, slow growth rate, bottom of wall)
Moisture content (weight%)
Weeks
S 23 A/W2N-d/M
S 23 A/W2N-d/M-3i
S 23 A/W2N-d/M-centre
S 23 A/W2N-d/M-3o

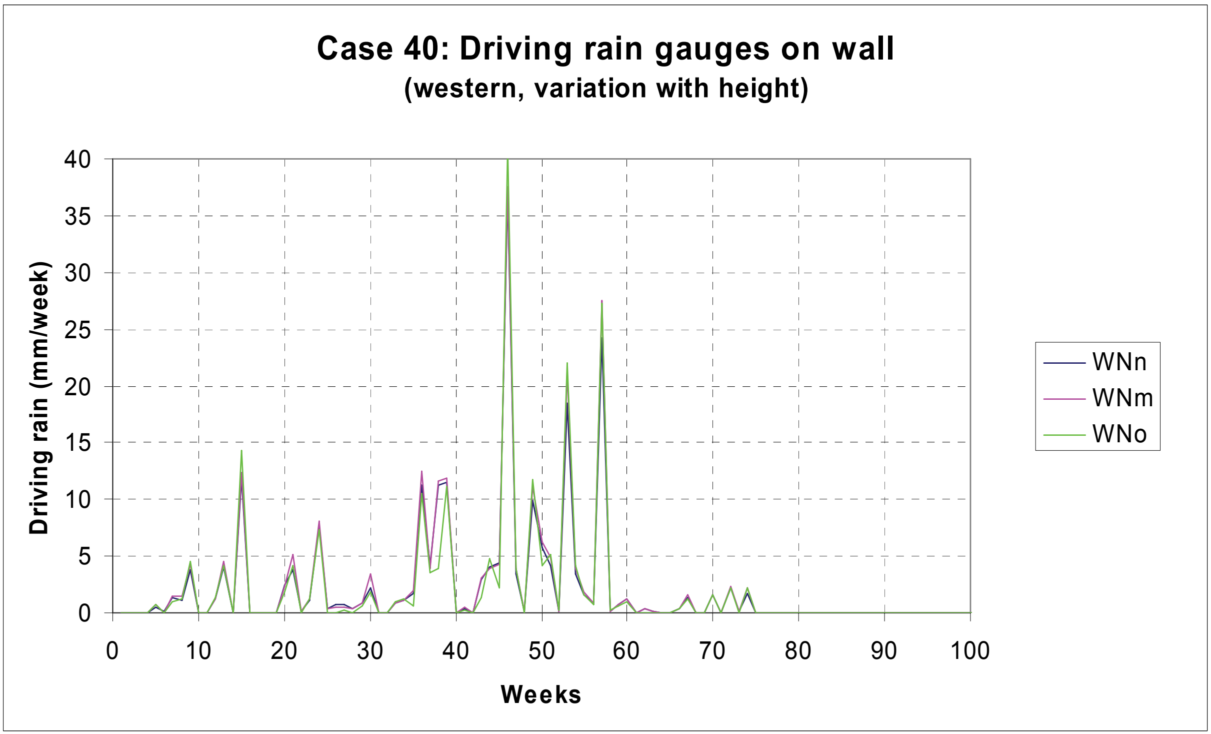

Case 37: Directional driving rain gauge (free field)
(mm driving rain from each direction)
Driving rain (mm/week)
Weeks
SrN
SrV
SrS
SrØ

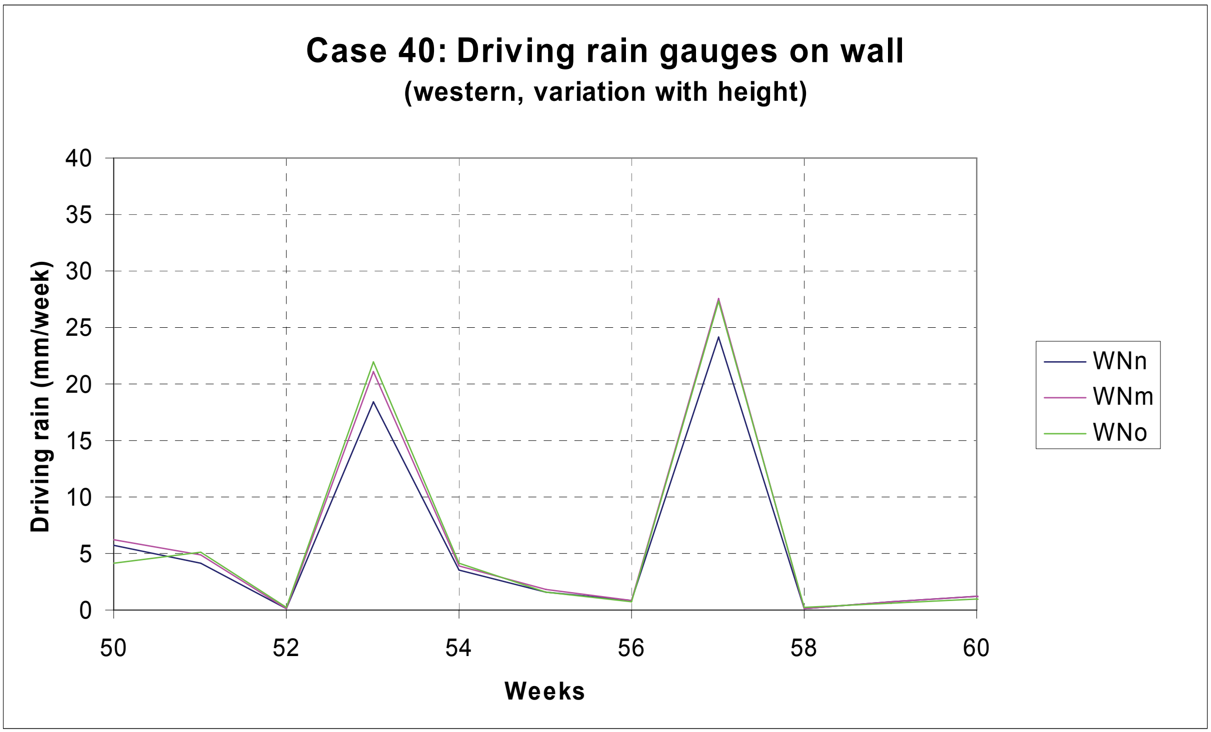

Case 38: Driving rain gauges on wall
(western and eastern orientation, middle of wall)
Driving rain (mm/week)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100
Weeks
W3Nm
E4Nm
WNm
W6Sm

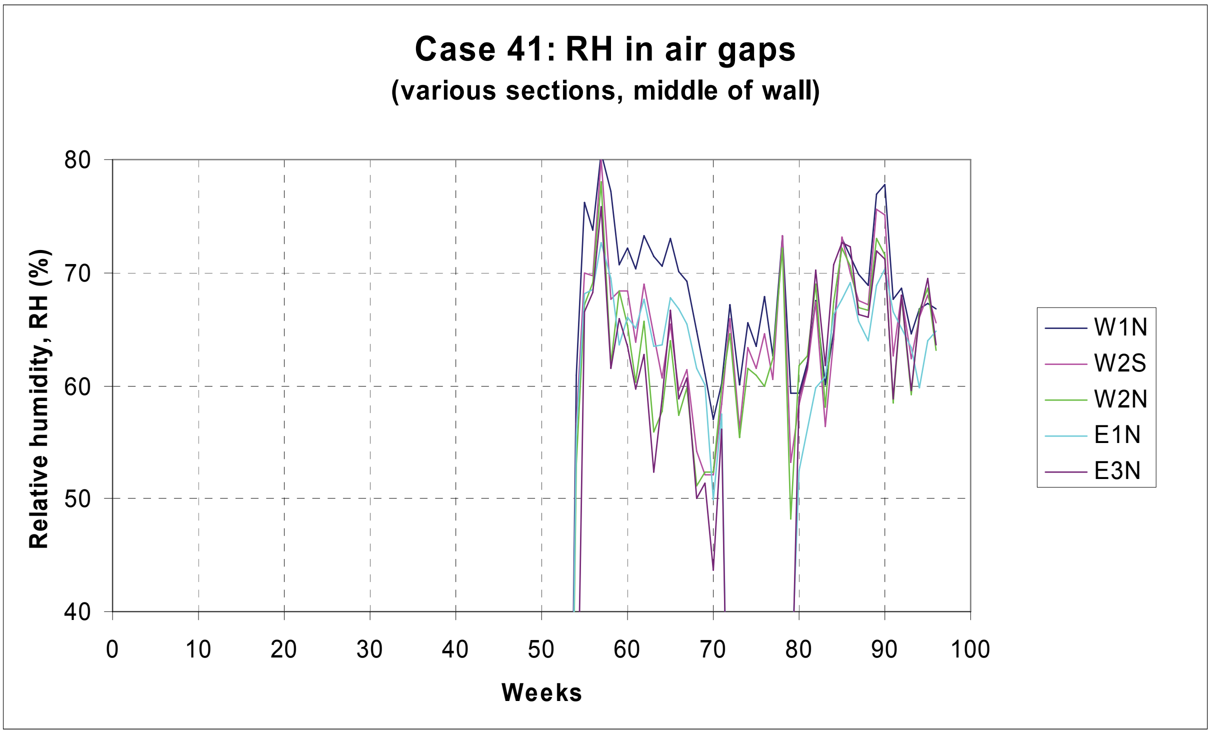

Case 38: Driving rain gauges on wall
(western and eastern orientation, middle of wall)
Driving rain (mm/week)
0
5
10
15
20
25
30
35
40
50
52
54
56
58
60
Weeks
W3Nm
E4Nm
WNm
W6Sm


Case 39: Driving rain gauges on wall
(western, variation with height)
Driving rain (mm/week)
Weeks
W3Nn
W3Nm
W3No
W3Nø
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100

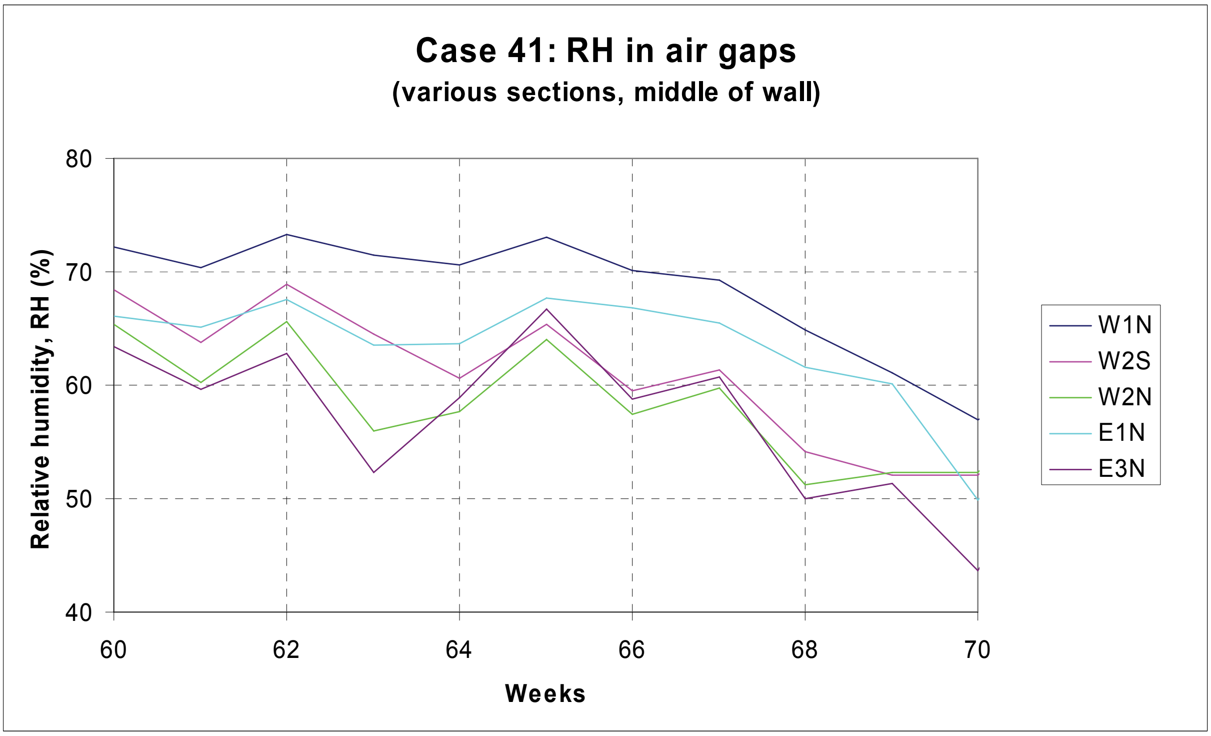

Case 39: Driving rain gauges on wall
(western, variation with height)
Driving rain (mm/week)
Weeks
W3Nn
W3Nm
W3No
W3Nø
0
5
10
15
20
25
30
35
40
50
52
54
56
58
60


Case 40: Driving rain gauges on wall
(western, variation with height)
Driving rain (mm/week)
Weeks
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100
WNn
WNm
WNo

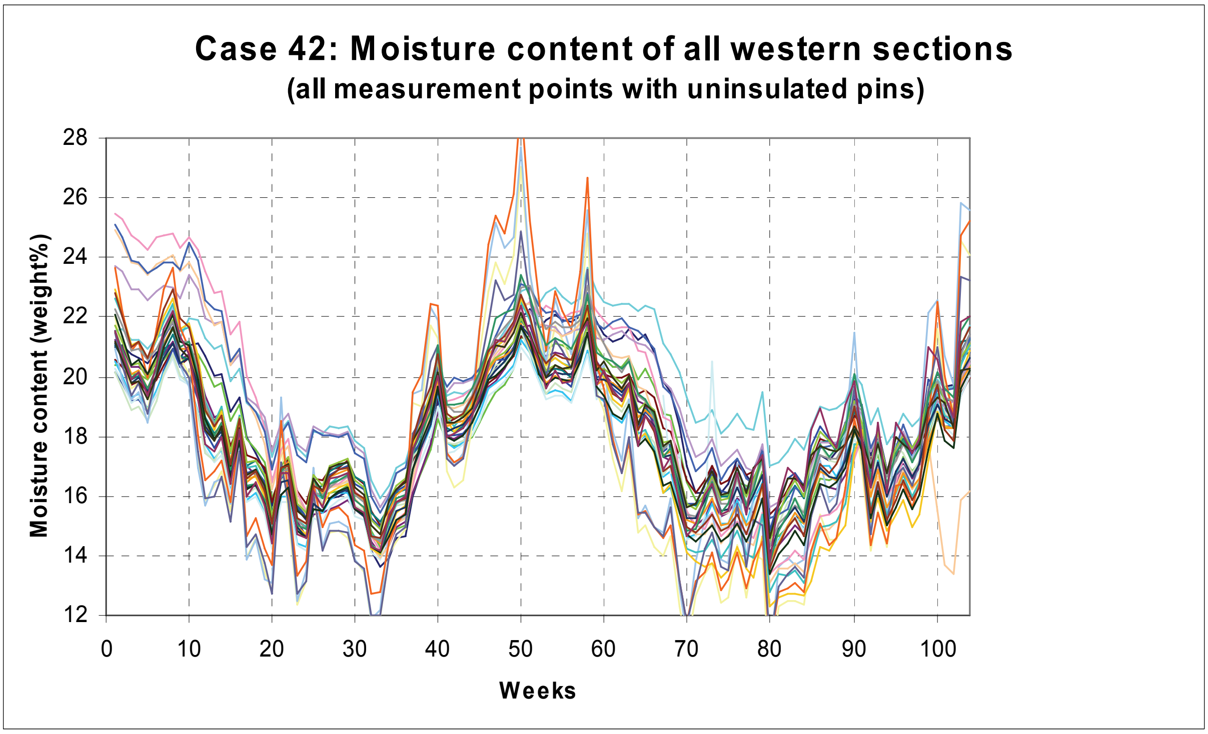

Case 40: Driving rain gauges on wall
(western, variation with height)
Driving rain (mm/week)
Weeks
0
5
10
15
20
25
30
35
40
50
52
54
56
58
60
WNn
WNm
WNo

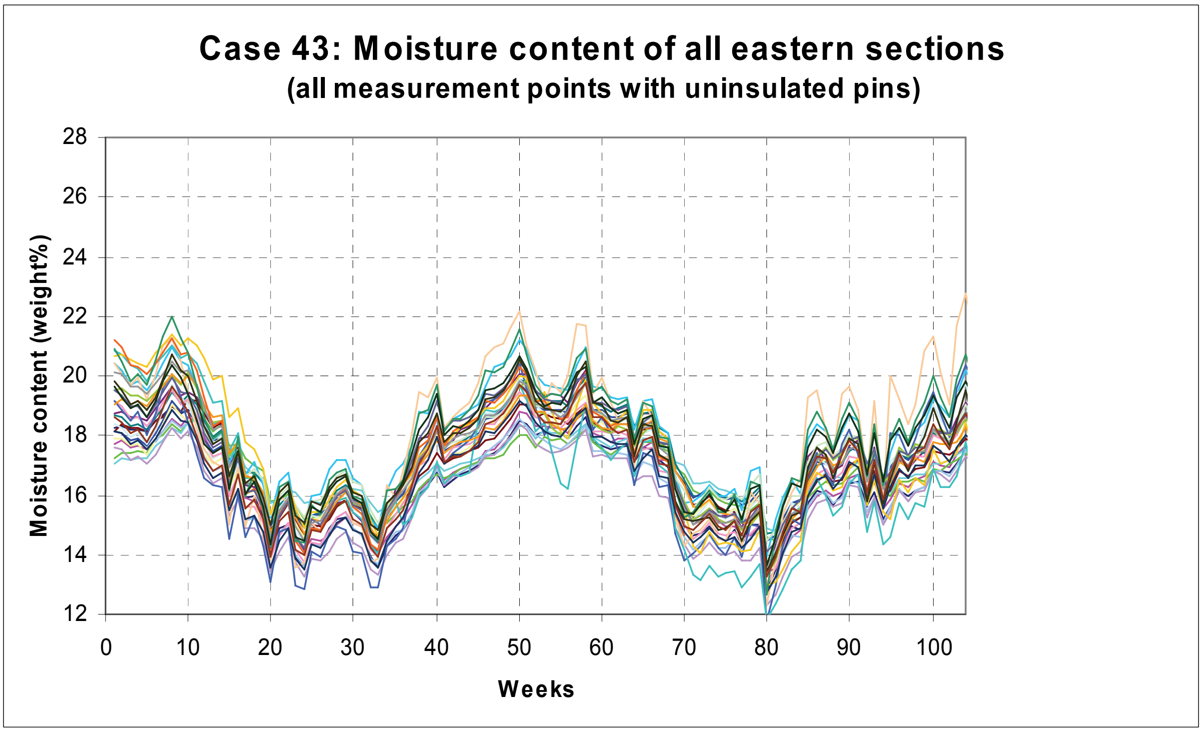


Case 41: RH in air gaps
(various sections, middle of wall)
Relative humidity, RH (%)
Weeks
W1N
W2S
W2N
E1N
E3N
80
70
60
50
40
0
10
20
30
40
50
60
70
80
90
100



Case 41: RH in air gaps
(various sections, middle of wall)
Relative humidity, RH (%)
Weeks
W1N
W2S
W2N
E1N
E3N
80
70
60
50
40
60
62
64
66
68
70


Case 42: Moisture content of all western sections
(all measurement points with uninsulated pins)
Moisture content (weight%)
28
26
24
22
20
18
16
14
12
0
10
20
30
40
50
60
70
80
90
100
Weeks


Case 43: Moisture content of all eastern sections
(all measurement points with uninsulated pins)
Moisture content (weight%)
28
26
24
22
20
18
16
14
12
0
10
20
30
40
50
60
70
80
90
100
Weeks