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A Catalogue for *Picea abies* exposed to the Climatological Standard Normal at 15 Positions

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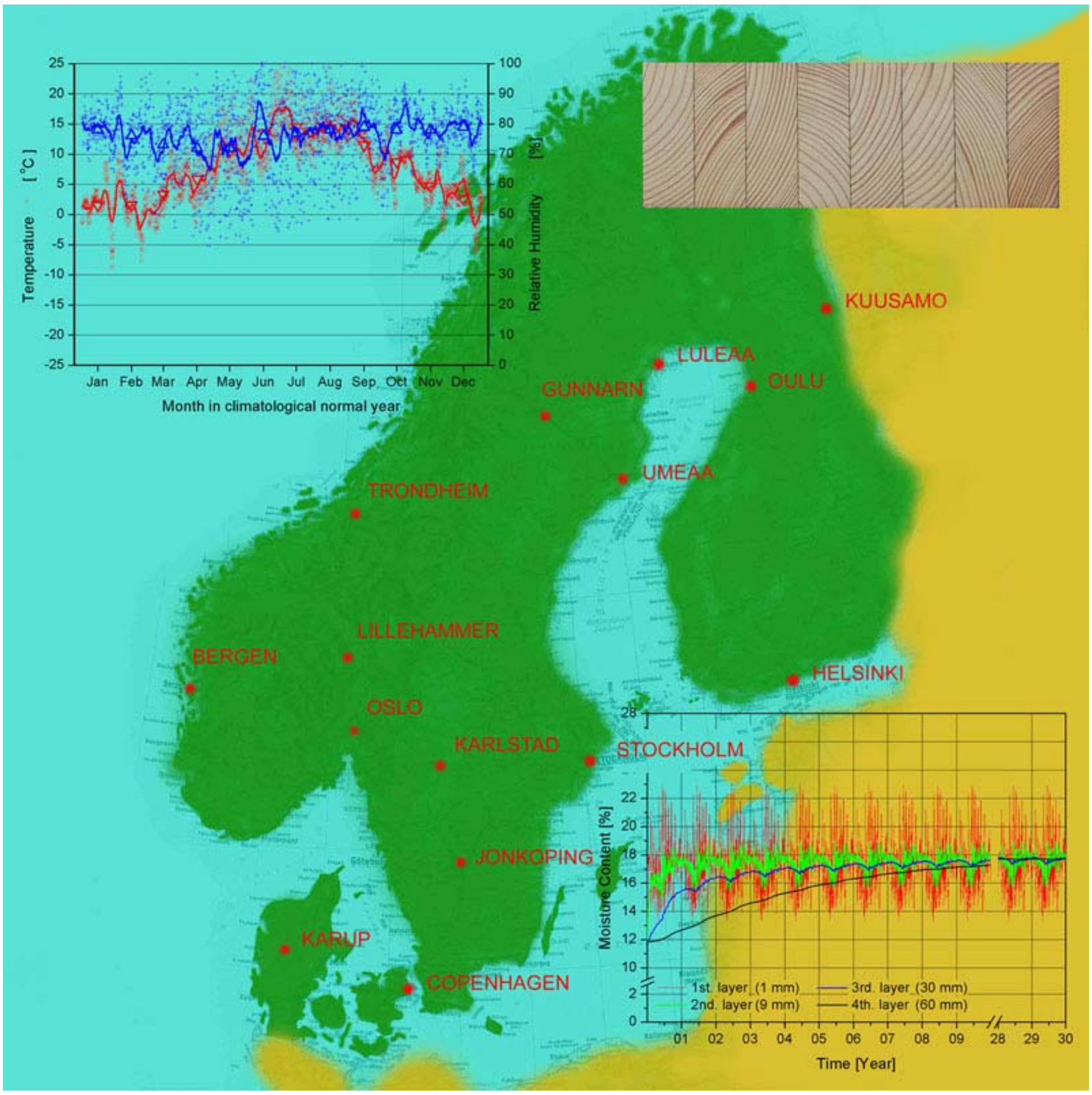

Technical Report SR-03-15

May 2003

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Preface

This report is one of the results of the project ”Parking facilities in timber, a feasibility study” (”Parkeringshus i trä, förprojekt”) financed by the Nordic Industrial Fund through project no. 020508 and by the below listed companies. The feasibility study enters as part of the work towards the introduction of timber constructions in parking facilities in the Nordic countries.

The goal of the project has been to estimate the marked potential and identify areas with foreseeable technical problems. An important part of the project has been to raise interest amongst decision makers for timber based parking facilities and to identify suitable pilot projects.

The following persons, institutes and companies have participated in the project:

Denmark	
Technical University of Denmark, BYG•DTU	Christian Clorius
Limtrae Danmark A/S	Martin Uhre Pedersen
Norway	
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Martinsons Trä AB	Greger Lindgren
Norra Massivträ	Håkan Johnson
Norra Massivträ	Nils-Olov Berglund
Trätek	Anders Gustafsson

Nordic Nordic Industrial Fund - *center for innovation and commercial development* is an institution under the Nordic Council of Ministers. The Fund initiates and finances projects and activities that create synergy between the actors in the Nordic innovation system.

It is our hope that the report will be of use for all working with timber structures.

Anders Gustafsson
Project manager

Summary

The background ideas for engaging in the present investigation can be summarized in the following two theoretical considerations:

- When wood members are exposed to variations in the ambient climate, (T,RH), the transient moisture content is a function of climate variations, *Clim(T,RH)*, permeability and member thickness, TMC(*Clim(T,RH)*,δ_p,*t*). The theoretical point is that the frequency of the variations in transient moisture content, f_{TMC}, in the general case will be out of phase with the frequency of the climatic variations, f_{clim}, and consequently lower amplitude of the TMC variation is expected.

- The moisture content dependency of the water vapour permeability, expressed in the $\delta_{p(RH)}$-relation, is expected to provide wood members with a moisture-pump or moisture-trap function. This is so, as the member surface is open for moisture uptake at high values of ambient RH and closed for moisture release at low values of ambient RH. The theoretical point is that the exponential growth of the $\delta_{p(RH)}$-relation will shift the mean level of the TMC towards the moist side when thick wood members are exposed to variations in the ambient climate.

The numerical studies laid forward in this investigation verify both these considerations. The numerical study comprises a parameter study show the effect of member thickness, loading frequency, magnitude of driving potential etc. at test climate conditions. The core of the investigation consists of modelling transient moisture content of a 100 mm symmetrical cross-section exposed one-sided to the outdoor climate at 15 Nordic positions for a period of 30 years. The climate history used is the climatological standard normal as defined by WMO. This investigation is presented as a catalogue for long-term transient moisture content in the Nordic countries.

The observation that the annual mean level long-term moisture content for timber elements with medium size or bigger cross-sections at outdoor covered conditions is highly influenced by the shape of the water vapour permeability relation, is a new discovery. This finding and the method applied form a theoretical basis for experimental model verification. When such verification/subsidiary model calibration has been employed, it will be possible based on the relatively refined models used in the present investigation to set up simple relations for determining the long-term moisture content for wood members as function of moisture load history and member thickness.

1 Introduction

The influence of moisture content on the mechanical behaviour of timber constructions is traditionally and according to the national as well as the European code (Euro Code 5 - ENV 1995-1-1, 2001) handled by the system of service classes and the corresponding modification factors. Whereas this system is very expedient and rational with respect to the strength and stiffness properties, there is a shortcoming of the system regarding the assessment of fluctuations of moisture content within the service classes. This assessment is needed both in the case where changes in moisture content give rise to global deformations of the structure, for an example see (Clorius, 2003), and in cases where moisture induced deformations give rise to internal stresses and hence, formally should be treated as a load case.

The need for design tools with respect to the long-term moisture equilibrium and fluctuations has become increasingly vivid as the experiences from design and service behaviour of solidwood constructions are being gathered these years. An exemplary illustration of the problems meet is seen in the solidwood roofing of the barns of the Danish agricultural museum “Gammel Estrup”. This roofing was designed with the best of knowledge including high moisture content at erection and initial inter-element gaps. However, the roofs exhibit a slight global moisture induced rise after a couple of years in service, Figure 1. The moisture content of the solidwood elements in this construction is being surveyed and is reported in a preliminary version in (Clorius & Ljørring, 2003).

Figure 1: Glued solidwood elements used as roof elements at outdoor covered climate conditions – a slight rise of the otherwise straight roof plane is observed, the rise is probably a function of restricted moisture swelling of the individual elements.

2 Background

The moisture content, MC, of wood is ultimately governed by the sorption-isotherm, including the de- and adsorption branch and hysteresis. These curves describe the equilibrium moisture capacity of the material as function of the ambient relative humidity, RH, at a given temperature. For small members, where equilibrium is rapidly obtained, and for relatively slow variations in RH it is appropriate to use the sorption-isotherm directly when assessing the variations in equilibrium moisture content, EMC.

When the wood members are of larger dimensions and when the variations in RH are relatively rapid the velocity of the vapour transport through the material becomes a bottleneck. Hence, in most practical applications the moisture content is not an EMC to be determined directly from the sorption-isotherm, but is a transient moisture content, TMC, that cannot be assessed without knowing the moisture history and the water vapour permeability, δ_p.

The water vapour permeability of wood is known to be a function of the moisture content, $\delta_{p(RH)}$. The dependency is so that the moister the material the more open for water vapour transport it becomes. This material property has an influence on the value of the TMC to the effect that the moisture content is biased towards the moist side.

Hence, the background ideas for engaging in the present investigation can be summarized in the following two theoretical considerations:

- When wood members are exposed to variations in the ambient climate, (T,RH), the transient moisture content is a function of climate variations, $Clim_{(T,RH)}$, permeability and member thickness, TMC($Clim_{(T,RH)}$,δ_{p},t). The theoretical point is that the frequency of the variations in transient moisture content, f_{TMC}, in the general case will be out of phase with the frequency of the climatic variations, f_{clim}, consequently lower amplitude of the TMC variation is expected.

- The moisture content dependency of the water vapour permeability, expressed in the $\delta_{p(RH)}$-relation, is expected to provide wood members with a moisture-pump or moisture-trap function. This is so, as the member surface is open for moisture uptake at high values of ambient RH and closed for moisture release at low values of ambient RH. The theoretical point is that the exponential growth of the $\delta_{p(RH)}$-relation will shift the mean level of the TMC towards the moist side when thick wood members are exposed to variations in the ambient climate.

These two theoretical considerations are in the present investigation attempted tested in a numerical study. Firstly, a small parameter study is engaged, targeted at exposing the principles outlined above. Secondly – but also in the present context primarily – a series of numerical investigations of the effect of exposing *Picea abies* to recurring cycles of the climatological standard normal at different Nordic locations is presented.

3 Objective

The prime objective of the present investigation has been to establish a catalogue for the long-term moisture equilibrium for Norway spruce (*Picea abies*) at outdoor covered conditions at different Nordic locations.

In this context “long-term equilibrium” should be read as an abbreviation for “stabilized long-term moisture content variation at conditions with repeated transient climate variations”. The objective being simply to determine mean level and amplitude of the annual moisture content variation when these have stabilized at conditions with recurring annual variations of the temperature and relative humidity of the ambient climate.

The core of the study is a numerical analysis of the development of MC as function of 30 years repeated loading with the temperature and relative humidity of 15 different Nordic locations. The loaded member is a 100 mm thick wood element with the applied load history as boundary condition on the one side and a symmetry condition at the other. All transport is modelled one-dimensional in the transverse direction. The symmetry condition, i.e. no heat or moisture flux, makes it possible to interpret the results as either valid for a 200 mm thick double exposed element or as valid for an element with a one-sided physical vapour barrier sealing. The first interpretation is e.g. a high 200 mm wide beam in a covered construction. The second interpretation is e.g. the deck of a parking facility such as presented in (NTI Report 51, 2002), where the top-cladding acts as vapour barrier and the heat 0-flux condition assumed in the model plays no practical role due to the low thermal capacity of the wood member.

Prior to this core investigation a number of small parameter studies is presented with the objective to present and exemplify the consequence of the two previously mentioned theoretical observations subsidiary to test the used software. The whole investigation is a numerical study using commercially available software and should be easily reproducible for variations of the boundary conditions or material properties.

Besides the results generated and conclusions drawn in the present report the investigation serves as the first iteration in a process of enhancing and calibrating the methods for determining MC levels and variations at the serviceability state. This process has at least two more steps namely:

1. Enhancing the current modelling tools by means of an inclusion of the temperature dependency of the moisture capacity.
2. Calibration of the modelling results such as laid forward in the present investigation, by means of a thought literature study and selected new field MC-measurements of long-term exposed wood members.

The first step is planned within the national Danish project “Modelling the effects of moisture and load history on the mechanical properties of wood” founded by the Danish Research Councils (Materials Programme). The second step suits an inter-Nordic project both as knowledge of local constructions is needed for new data sampling and as relatively many measurements have already been made – but are unpublished and would gain from becoming available in a unifying context.

4 Method

4.1 Modelling moisture content at transient climate conditions

The modelling of moisture content has been performed by use of the software MATCH - a commercially available software targeted at "Moisture and Temperature Calculations for Constructions of Hygroscopic Materials (Andersen & Rode, 2002). The program is able to model one-dimensional non-Fician transient moisture transport by use of the finite element method. In the present context the software has the following functionalities:

- Sorption-isotherm can be defined with an ad- and desorption branch.
- Hysteresis can be included
- A moisture dependent permeability can be defined.
- The load history can be defined in time series for temperature and relative humidity covering a year with data points in one-hour intervals.
- The load history can be repeated infinitly.

The shortcomings of the software are:

- Only one sorption-isotherm can be defined per material.
  There is no possibility for taking the influence of temperature in the EMC into consideration directly. It should however be observed that had this functionality been present – the practical problem of obtaining reliable experimental data at other temperatures than 20 ˚C would remain.
- The effect of convection is neglected.
- The software does not consider the velocity of sorption.
  This shortcoming has however probably no practical implications for timber dimensions as the vapour transport velocity is much slower than the sorption velocity, for a discussion of sorption velocity see (Krabbenhøft, 2003).

4.2 Material parameter settings in MATCH modelling

4.2.1 General settings

The general settings of the input data are shown in Appendix 1, the settings are constructed to secure that the only climate load applied is ambient air temperature and ambient relative humidity. The initial moisture content condition is set to 11.87% for all modelling engaged, a value corresponding to equilibrium with 63% RH at the adsorption branch of the sorption-isotherm.

The boundary condition at the exposed side of the exposed element is the applied load history – defined in the climate file, at the other side of the element a non-flux boundary condition is applied, i.e. a layer with infinite water vapour resistance and infinite thermal resistance. The non-flux condition corresponds to a symmetry condition and makes it possible to interpret the results either as valid for double sided exposure of elements of double thickness or as valid for elements with the prescribed non-flux boundary condition. In case of the latter interpretation the thermal non-flux condition is of minor importance and the results apply to objects such as decking in parking facilities, where de top-layer coating secures the water vapour non-flux condition.

4.2.2 Sorption characteristic

Standard values for the sorption-isotherm for *Picea abies* with a mean density of 420 kg/m³ at 20 ˚C are used. The sorption isotherm is based on values from (Ahlgren, 1972) and is shown in Figure 2.

The program code handles scanning curves by an empirical approach using the weighted values of the slope of the ad- and desorption branch:

(1) $$\xi_a = \frac{\partial u_a}{\partial \phi} \quad \text{and} \quad \xi_d = \frac{\partial u_d}{\partial \phi}$$

When the most recent moisture history – the two preceding time steps – show an increase in MC the slope of the adsoption scanning is determined by:

(2) $$\xi_{hys,a} = \frac{0{,}1(u-u_a)^2 \xi_d + (u-u_d)^2 \xi_a}{(u_d-u_a)^2}$$

Where u_a and u_d are the moisture contents on the absorption and desorption curves corresponding to the current relative humidity, and u is the most recently determined moisture content. Correspondingly, the slope of the desorption scanning curve is determined by:

(3) $$\xi_{hys,d} = \frac{(u-u_a)^2 \xi_d + 0{,}1(u-u_d)^2 \xi_a}{(u_d-u_a)^2}$$

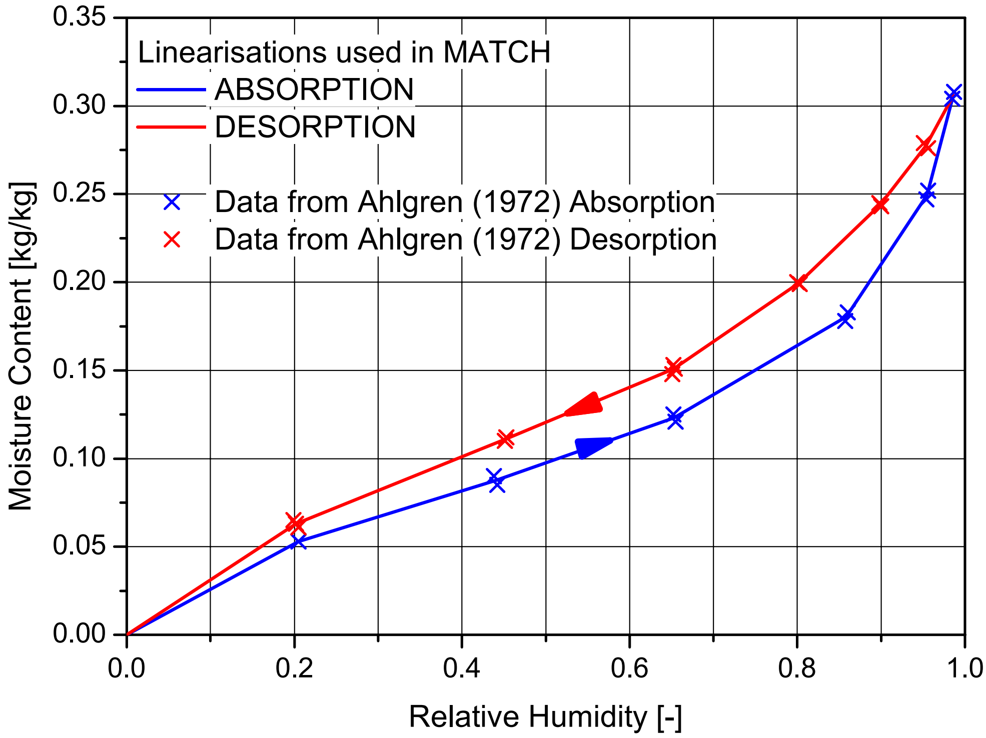

Figure 2: Experimental data for EMC determined in ad- and desorption from (Ahlgren, 1972), here quoted from (Kielsgaard Hansen, 1986). The values are determined at 20 ˚C on Picea abies with a mean density of 420 kg/m³. The sorption isotherms used in MATCH is the shown linearisations.

4.2.3 Water vapour characteristic

The water vapour characteristic is determined on basis of a regression on experimental data for *Picea abies* with mean density in the range 400-430 kg/m^3 determined at 20-25 ˚C. The data stems from cup-tests reported by (Tveit, 1966), (Hedenblad, 1996) and (Fynholm & Clorius, 2002), all data are shown in Figure 3. In the regression the data from (Fynholm & Clorius, 2002) is given more weight, as these data are generated by use of an experimental set-up where in the order 100 times more material is tested.

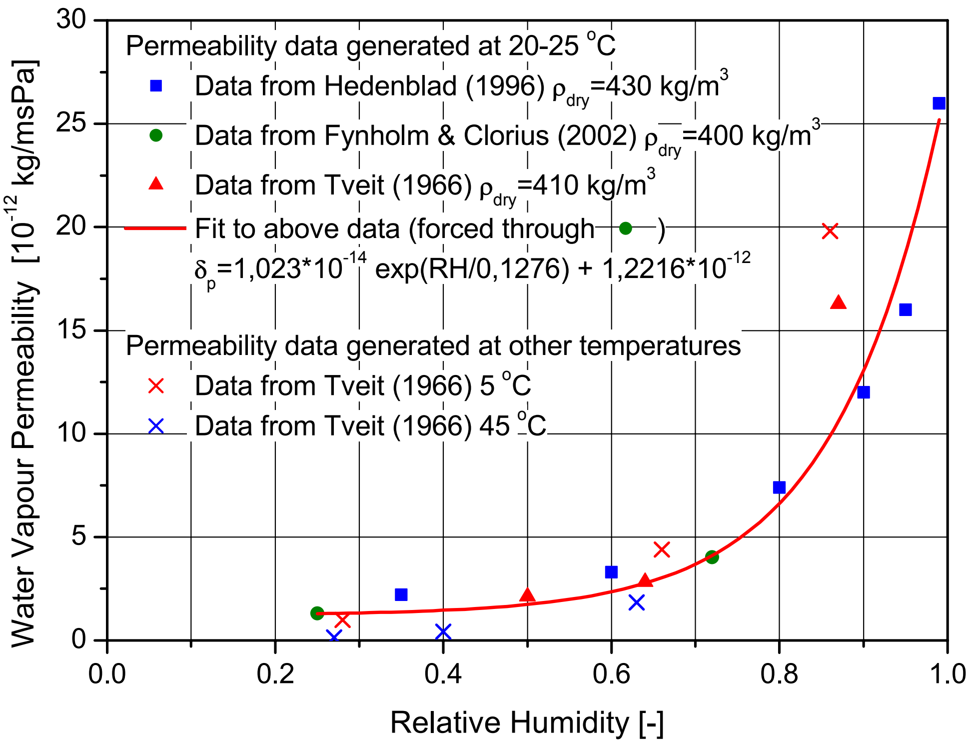

Figure 3: Experimental data and derived water vapour characteristic as function of relative humidity for Picea abies perpendicular to the grain.

4.3 Parameter study

4.3.1 Influence of model coarseness

The influence of model coarseness is assessed in a parameter study using the test climate history shown in Figure 4 applied to three 100 mm thick models differing with respect to element fineness. The modelling results are shown in Figure 5. The study shows no measurable effect of increasing the model fineness by doubling the model refinement from 40 to 80 sub-layers; hence, a 4-layer model with 10 subdivisions is used in the core investigation. The layer-thickness is chosen so as to have fines elements towards the loaded side of the model; the subdivision scheme automatically employed is shown in Appendix 2.

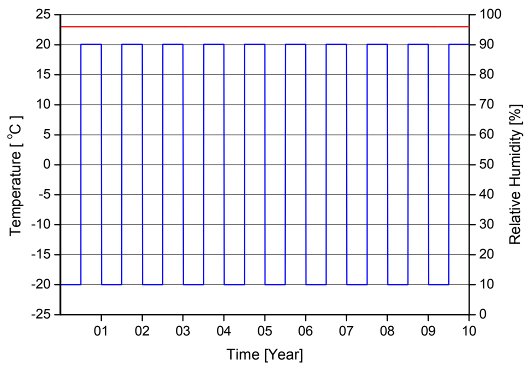

Figure 4: Test climate with annual RH oscillations between 10% and 90% (90,2%) at a temperature of 23 ˚C – shown over a period of 10 years – climate data file contains data at one-hour intervals.

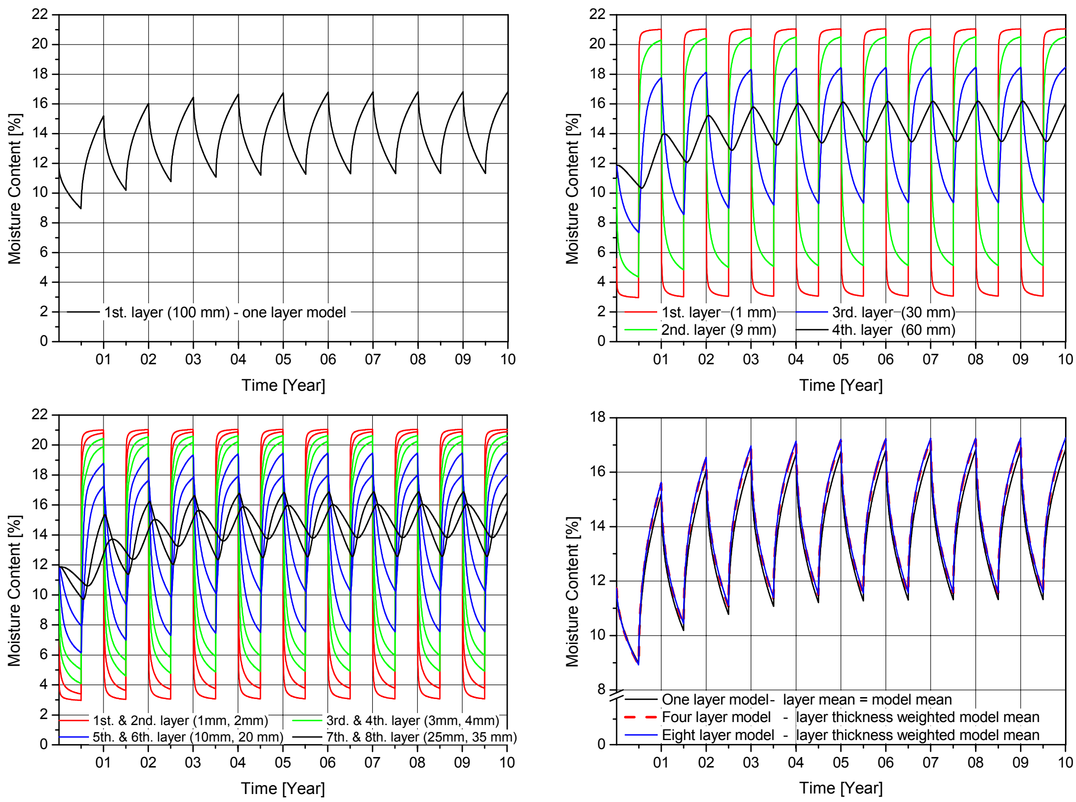

Figure 5: MC response for each layer of three models exposed to the test climate in Figure 4, and the resulting model mean variation. The models differ in layer fineness ranging from one to eight all with 10 subdivisions. All modelling have been made neglecting hysteresis using only the absorption branch, shown in Figure 2.

4.3.2 Influence of member thickness

The effect varying the thickness of the member exposed to the test climate given in Figure 4 is shown as model mean MC response in Figure 6. The modelling has been made neglecting hysteresis using the absorption-branch of Figure 2.

The EMC of the absorption branch at 23 ˚C and 10% RH is 2,6% and 21,1% for 90,2% RH. The modelling results shows that a 20 mm model almost oscillates between these values – thought the dry state never reaches the dry EMC. The larger resistance for moisture transport in the dry state is directly visible as a smaller value of the $\partial u/\partial t$ gradient in drying. For larger thicknesses the mean value of the TMC increases whereas the amplitude decreases. A mean value/amplitude summary for the long term TMC is given in Table 1.

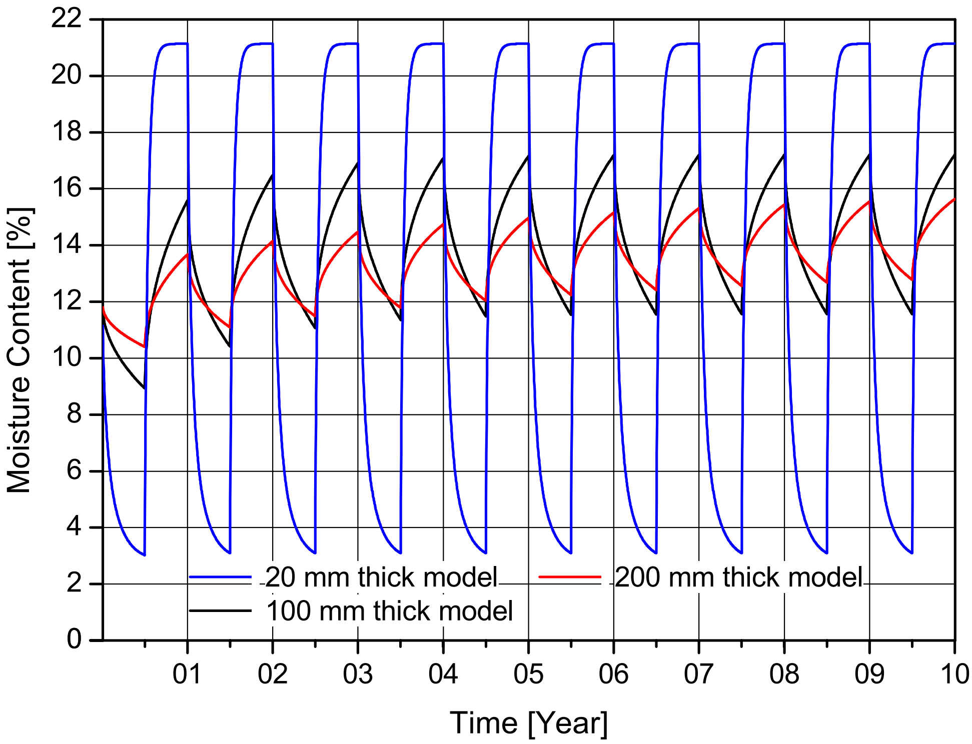

Figure 6: MC response whole model in dependency of model thickness, all of three models have been exposed to the test climate in Figure 4. All modelling have been made neglecting hysteresis using only the absorption branch, shown in Figure 2.

Table 1: Long term transient equilibrium moisture content response for three model thicknesses when exposed to the model climate of Figure 4.

Model thickness [mm]	20	100	200
Long-term annual MC mean [%]	12,1	14,4	14,2
Long-term annual MC amp. [%]	±9	±2,9	±1,4

4.3.3 Influence of loading frequency

Increasing the frequency of loading shall in principle have the same effect of the mean value and amplitude of the TMC as increasing the model thickness. Figure 7 shows results for a 20mm and 100 mm model loaded with the model climate in Figure 4 – same results as given in Figure 6, and with the same climate values at a 5 times higher frequency. Increasing the frequency clearly increases the mean value and narrows the span of the TMC oscillation. A mean value/amplitude summary for the long term TMC is given in Table 1.

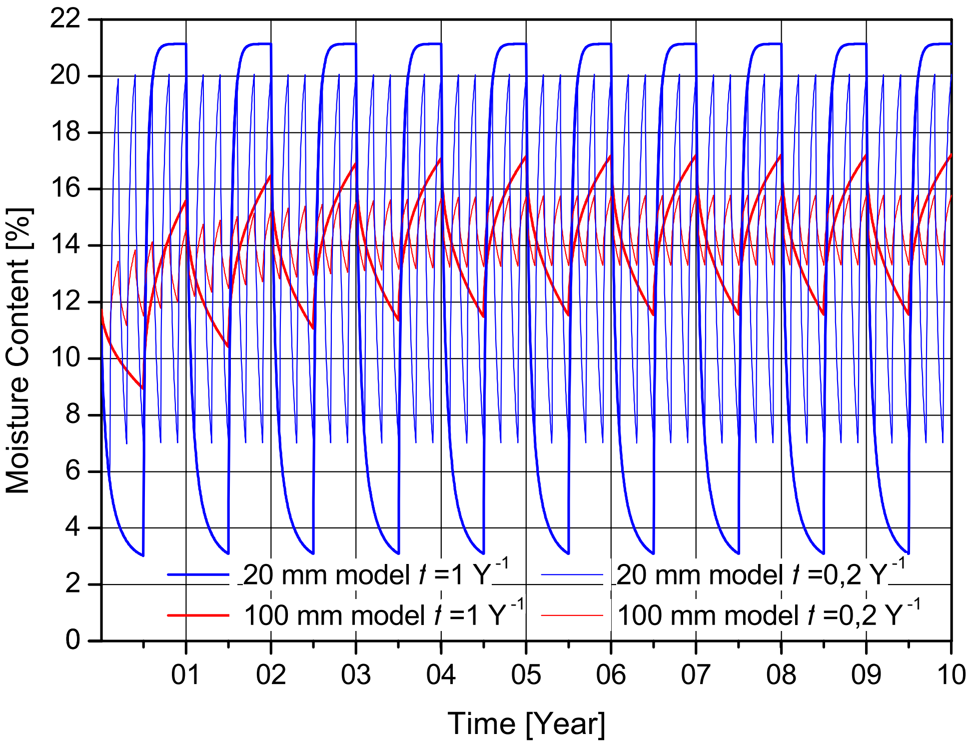

Figure 7: MC response whole model in dependency of frequency of climate loading. A 20 mm and a 100 mm model have been exposed to RH oscillations between 10% and 90 % at a frequency corresponding to 1 annual cycle (as the model climate in Figure 4) and 5 annual cycles. Temperature is held constantly at 23 ˚C. All modelling have been made neglecting hysteresis using only the absorption branch, shown in Figure 2.

Table 2: Long term transient equilibrium moisture content response for two model thicknesses when exposed to the model climate of Figure 4 and same a climate with same shape and extreme values but a 5 times higher frequency.

Model thickness [mm]	20		100	
Frequency of loading [Y^{-1}]	1	0,2	1	0,2
Long-term annual MC mean [%]	12,1	13,5	14,4	14,6
Long-term annual MC amp. [%]	±9	±6,5	±2,9	±1,2

4.3.4 Influence of hysteresis

In the preceding three sections modelling were made neglecting the effect of hysteresis in order to show the effects of model fineness, model thickness, and frequency of loading history in an as pure form as possible. In Figure 8 the previously presented modelling result for a 100 mm model exposed to the model climate of Figure 4 neglecting hysteresis is presented along with the result including hysteresis. Clearly, the effect of hysteresis augments the observed “moisture trap”-effect as moisture is stronger bound to the cells in desorption, compared to the forces with which it is adsorbed in absorption.

The effect of including hysteresis compared to modelling using only the absorption branch seen in Figure 8 is summarized in Figure 9 showing model mean MC.

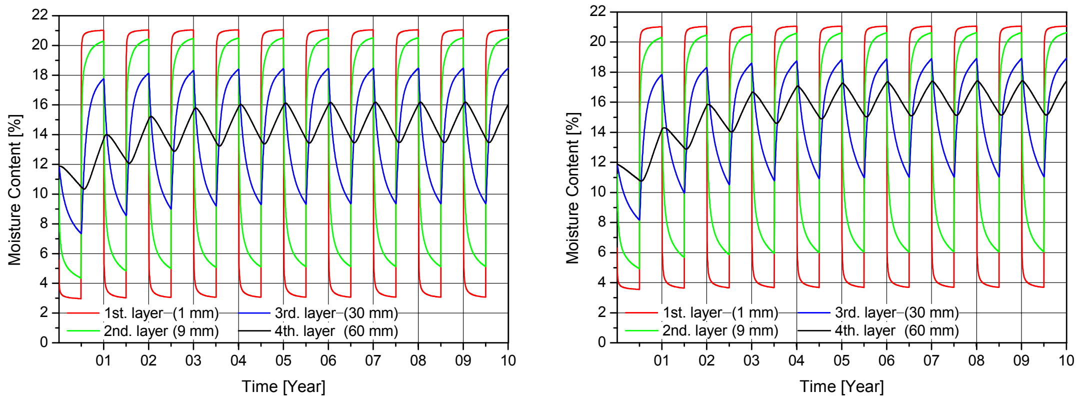

Figure 8: 100 mm Picea abies exposed one-sided to the test climate shown in Figure 4. Modelling made without hysteresis (left) using the absorption branch of Figure 2 and including hysteresis (right) using both branches of Figure 2. Results given for a four layer model for 10 years.

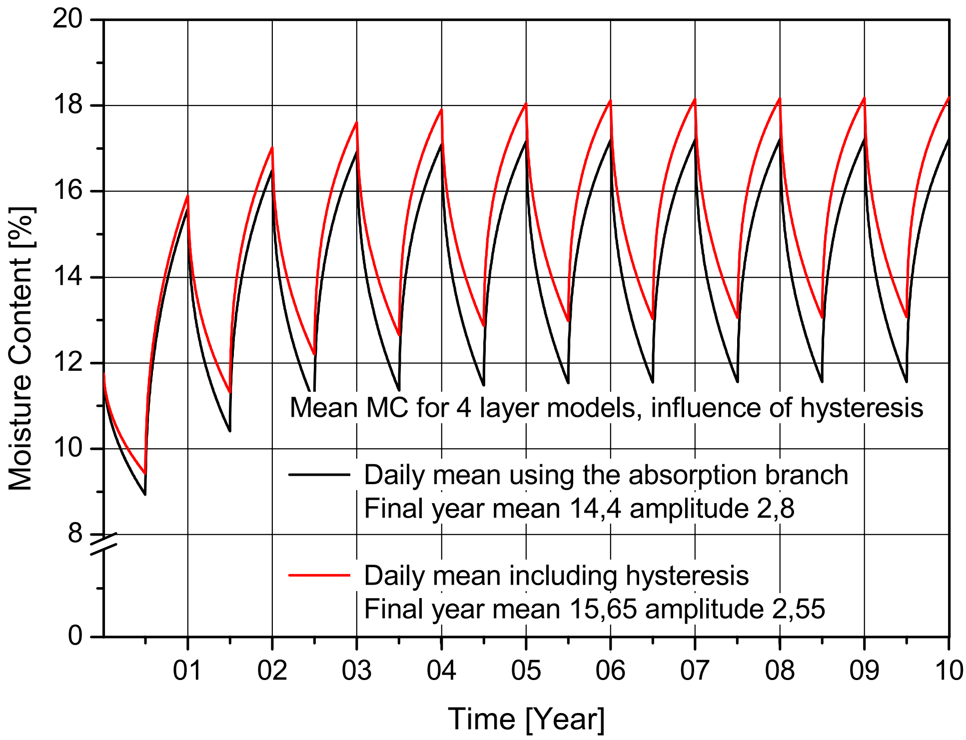

Figure 9: Effect of including hysteresis in the modelling. Mean model moisture content for models shown in Figure 8.

4.3.5 Influence of temperature

The temperature has no direct effect on the moisture capacity of the modelled material as the software used only gives the possibility for defining one sorption isotherm per material. However, indirectly the temperature has a large effect on the TMC. This is so, as the transient moisture content is a dynamic quantity lying within the bounds of the moisture capacity defined by the sorption isotherm but in most practical cases determined by the speed of water vapour transport. Hence, as the transport velocity is governed both by the value of the permeability and the potential available for driving the transport, the TMC is to a large extend governed by the temperature.

In Figure 10 the previously presented results for a 100 mm model exposed to the test climate of Figure 4 is shown for a period over 60 years. Clearly, a stable TMC conditions is reached within the first 5-10 years. For the same relative humidity conditions but at a temperature of -10˚C a stable condition is not reached within the first decade. The model mean value is given in Figure 11 along with long-term annual mean and amplitude. The decrease in amplitude for decreasing temperature is the direct effect of the smaller driving potential, whereas the adjoining increase in mean TMC for low temperature is the effect of the asymmetry of the water vapour permeability function being more pronounced at low values of the driving potential.

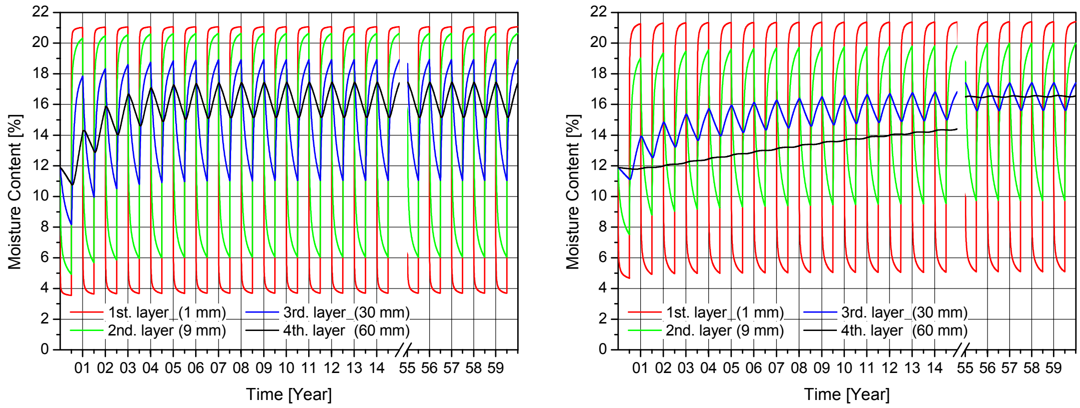

Figure 10: 100 mm Picea abies exposed one-sided to a test climate with RH oscillations between 10% and 90 % as shown in Figure 4 at a temperature of 23 ˚C (left) and a temperature of -10 ˚C (right).

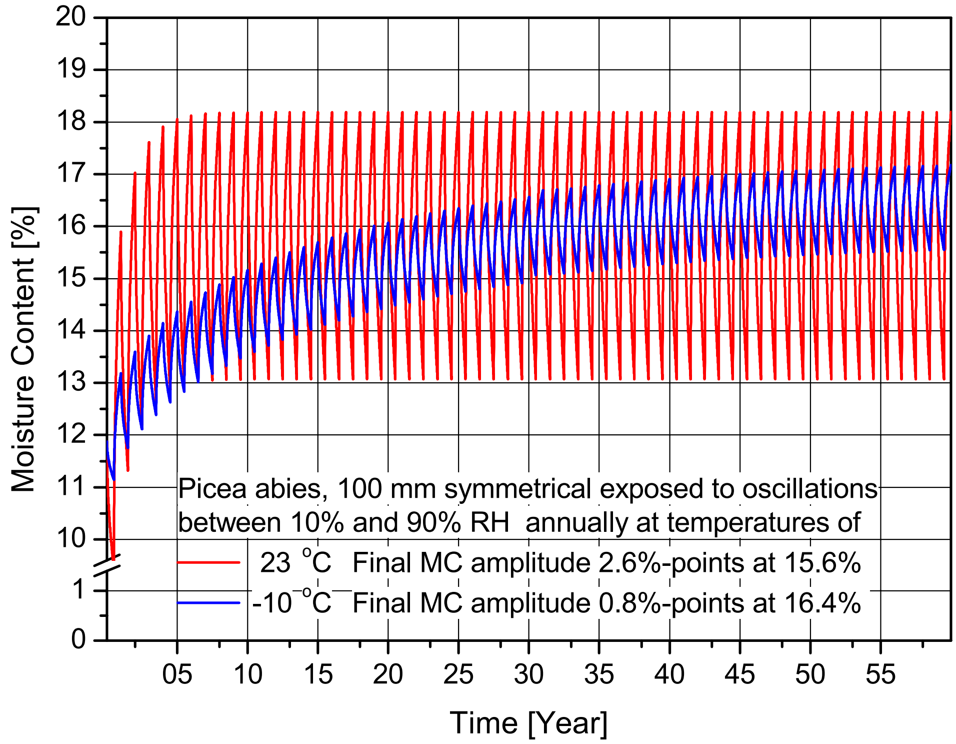

Figure 11: Effect of temperature on the model mean moisture content. Shown over a period of 60 years for100 mm Picea abies exposed one-sided to the test climate with annual RH oscillations between 10% and 90 % at temperatures of 23 ˚C and –10˚C.

4.3.6 Influence of the shape of the δ_p(RH)-relation

In Figure 12 the linearization of the empirical water vapour permeability function given in Figure 3 is shown along with a left and right shifted perturbation. Figure 13 shows the result of modelling a 100 mm element using all three variants of the

δ_p(RH)-relation. An increase in annual mean MC is observed when the function is shifted towards right. This result pinpoint the main point throughout the preceding sections, namely that the shape of the δ_p(RH)-relation introduces an asymmetry between dry and wet periods resulting in higher long-term mean transient moisture content when the load history is a recurring oscillation between a dry and a wet state.

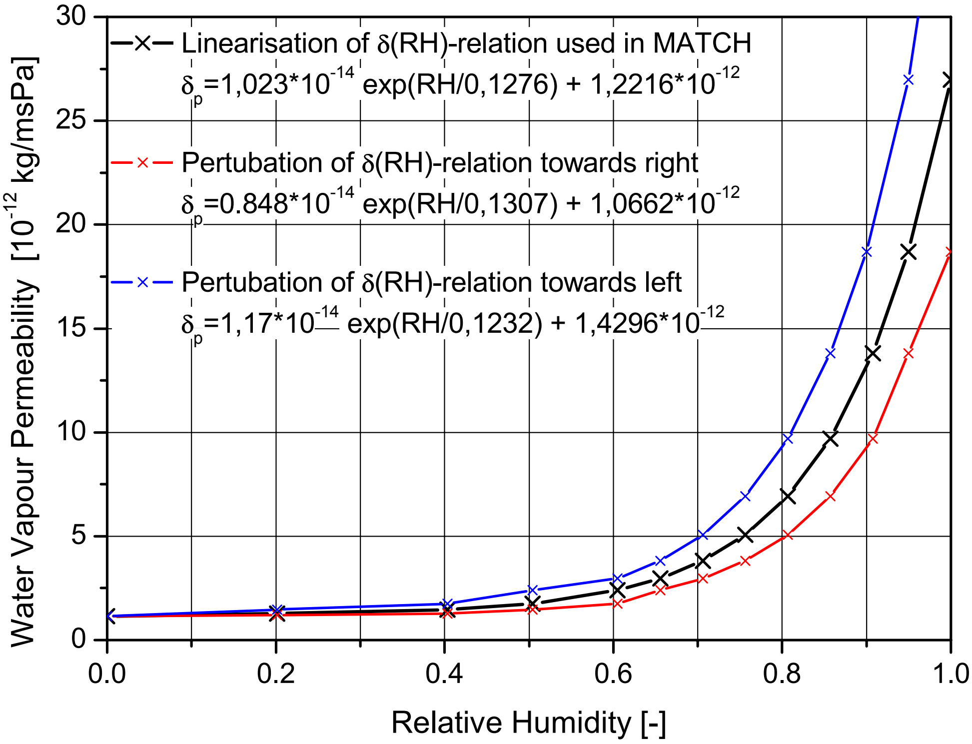

Figure 12: Linearisation of empirical δ_p(RH)-relation with right and left shifted perturbation.

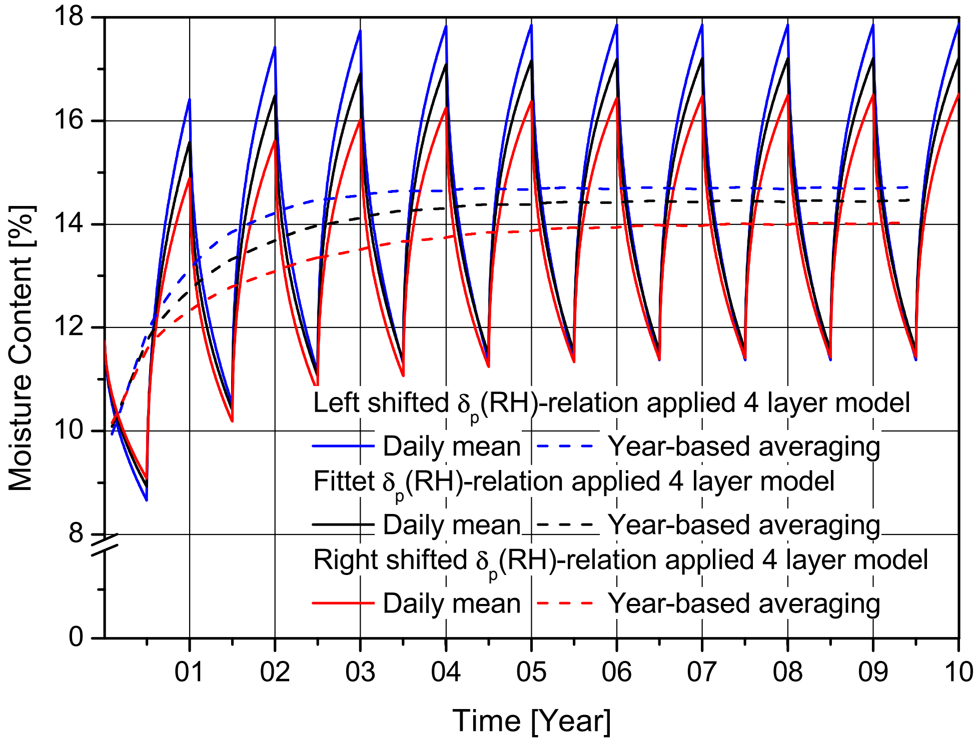

Figure 13: Effect of right and left shift pertubation of the δ_p(RH)-relation as given in Figure 12 on a four layer100 mm model exposed to test climate history as given in Figure 4. The modelling has been without hysteresis using the absorption branch.

Time series for the climate load

4.3.7 Climatological standard normals - CLINO

Modelling of long-term transient moisture content has been based on time series for air temperature, T_a, and relative humidity or dew point temperature, T_d. These time series are in most cases based on the monthly values of the World Meteorological Organization's climatological standard normal for the different locations determined in the reference period 1961-1990, (WMO, 1996). For some locations where a WMO series is not available a provisional normal has been used. Origins of the basis-data are clearly indicated in the presentation of the standard normal values.

4.3.8 Generating hourly values based on CLINOs

MATCH software is able to make use of climatological data for air temperature and dew point given on an hourly basis. The time series for T_a and T_d has been generated by use of the METEONORM software/database. The software allows a stochastic generation of time dependent values having a quasi-natural distribution based on monthly averages. METEONORM is able to write the generated time series directly in the input format used by MATCH, a description of software and database are given in (Remund, Kunz & Lang, 1999).

METEONORM is primarily directed at solar data and dependent parameters such as dew point are inflicted with greater error than the primary parameters. As the output needed for the MATCH modelling is air and dew point temperature the time series has been generated in an iterative procedure aimed at tuning the generated RH-values to meet the CLINO values. The procedure includes firstly a generation based on unadjusted internal setting of the program, i.e. only location is specified and the program uses the internal database values, secondly a generation tuned by use of new user defined input for values with error, see Table 3.

Table 3: Example for the two-step iterative procedure for determining time series for air temperature and relative humidity by use of METERONORM and the CLINO from WMO. The example shows values for Helsinki-Vantaa, WMO station no.02974.

	Unadjusted METEO-NORM values		WMO CLINO values		Difference WMO – METEO-NORM		New user input	Adjusted METEO-NORM values		Final error
	T [ºC]	RH [ºC]	T [ºC]	RH [%]	T [ºC]	RH [%]	RH [%]	T [%]	RH [%]	RH [%]
January	-6,9	86,6	-6,9	88	0,0	-1,4	89,4	-6,93	88,3	0,3
February	-6,8	84,4	-6,8	86	0,0	-1,6	87,6	-6,84	86,1	0,1
March	-2,9	79,8	-2,9	82	0,0	-2,2	84,2	-2,89	82,1	0,1
April	2,9	73,2	2,9	74	0,0	-0,8	74,8	2,86	75,0	1,0
May	9,9	64,6	9,9	65	0,0	-0,4	65,4	9,90	64,7	-0,3
June	14,9	66,1	14,9	66	0,0	0,1	65,9	14,91	66,0	0,0
July	16,7	72,0	16,6	72	-0,1	0,0	72,0	16,66	72,0	0,0
August	15,0	78,2	15,0	78	0,0	0,2	77,8	15,00	78,0	0,0
September	10,0	83,9	10,0	84	0,0	-0,1	84,1	9,97	84,0	0,0
October	5,4	85,8	5,4	86	0,0	-0,2	86,2	5,40	86,0	0,0
November	0,1	88,1	0,1	89	0,0	-0,9	89,9	0,11	89,0	0,0
December	-4,1	87,8	-4,1	89	0,0	-1,2	90,2	-4,10	89,1	0,1

The example given in Table 3 is typical and shows that the first unadjusted generation yields correct monthly standard values of T_a but values of T_d that deviates slightly from the CLINO values. The errors on the dew point temperature were observed to correspond to a maximum of 2,5 %-points deviation on the relative humidity – largest deviation in the cold months. In the second iterative generation the user target input for RH is given with a value corresponding to the WMO CLINO value added the deviation observed from the first generation. By these means a final time series is generated with a negligible error on the month mean CLINO values.

4.3.9 MATCH interpretation of generated series

The time series for air temperature and relative humidity generated by use of METEONORM is used as climate load boundary condition in the MATCH modelling. As a control for correct interpretation Figure 14 shows values for the imposed load history (only plotted in four-hour intervals) and the MATCH output values for temperature and relative humidity at a fictitious control layer placed at the load side of the used standard model. The values shown in Figure 14 are from the first half-year of the Helsinki position – same load history as given on a monthly basis in Table 3. A fine correspondence between imposed load history and out-interpretation is observed.

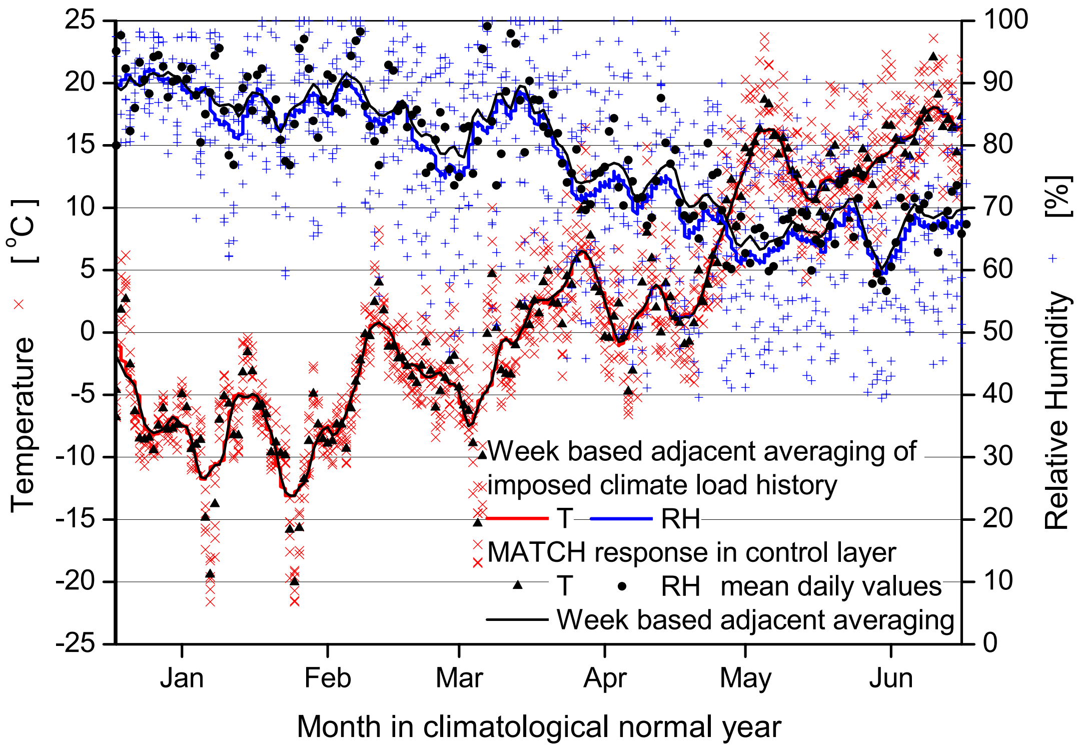

Figure 14: Comparison of imposed climate load history and the corresponding MATCH interpretation in a control layer at the surface of the exposed side. In the figure the load history is given with data in four-hour intervals – the input file contains however hourly values. The MATCH control-layer response is only available at a daily basis.

4.3.10 Modelled and measured MC for a thin member

This investigation is primarily a numerical study for later calibration with measured values, however in Figure 15 an informative example for modelled and measured values for a 20 mm thick member double sided exposed to climate at Danish outdoor covered conditions in Taastrup, Copenhagen. The measured values for MC shown in Figure 15 are taken from the midterm reporting of a five-year durability project at the Danish Technological Institute, (Lindegaard & Morsing, 2003). Each plotted value represents mean measured values of 10 boards (20x120x1000mm) half oriented towards south and half towards north. The high-density specimens are Swedish grown *Picea abies* with a mean density of 925kg/vol and the low-density are Danish grown with mean density 843kg/vol.

It is observed that the measured MC for autumn and winter lies between the modelled MC series for the two Danish positions. The summer measurements are generally 2%-points lower than the modelled. Clearly, as observed from the previously presented parameter studies, the mean MC for a 20 mm board is highly susceptible to deviations from the climatological standard normal. Hence, the accuracy of the employed procedure for MC-modelling cannot be judged by readings in Figure 15. However, the long-term MC-modelling for thick members presented in the proceeding sections is – due to the inertia with respect to the MC-response to annual climatic deviations – expected to yield predictions that should correspond fairly accurately to measurement on correspondingly long-term exposed members of same dimensions. That is of course stipulating the model assumptions in gross correct.

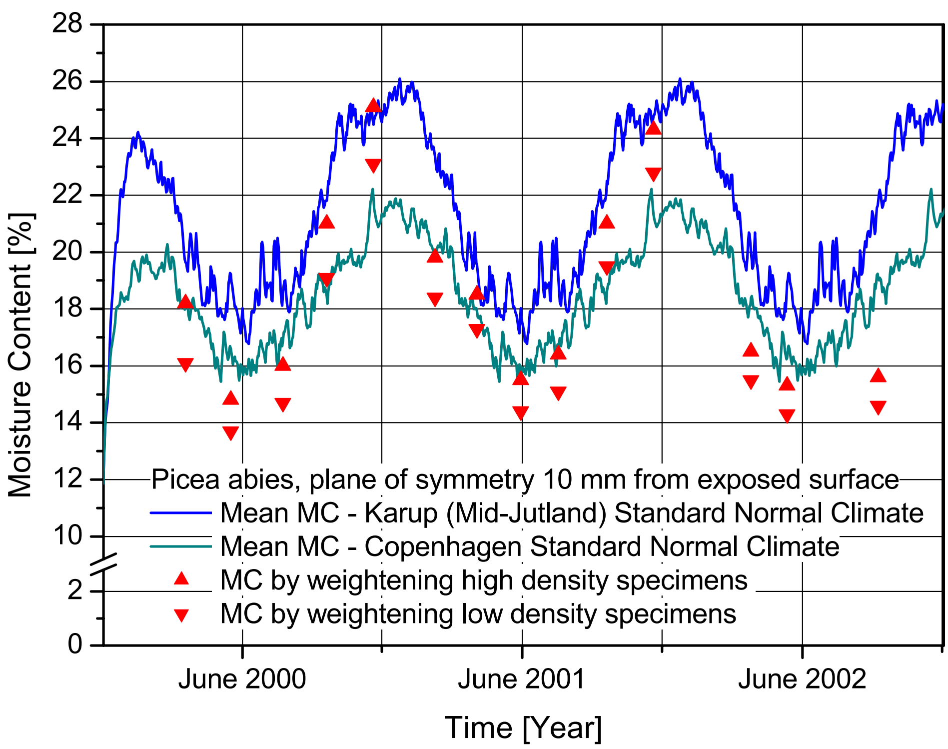

Figure 15: Comparison of measured and modelled moisture content, the latter generated by use of the climatic standard normal in both Karup and Copenhagen.

5 Modelling of long-term MC in Nordic countries

5.1 Denmark

Table 4: Summary of climatic standard normal for the modelled Danish positions. The mean values on a monthly basis are quoted from (WMO, 1996), same as given in (Laursen, Thomsen, & Cappelen, 1999), where the latter gives more detailed explanations to data sampling and the construction of the standard normal.

Position	Copen-hagen		Karup	
WMO-No.	06180		06060	
Altitude Latitude Longitude	5 m 55.37 N 12.39 E		53 m 56.18 N 09.07 E	
	T [ºC]	RH [%]	T [ºC]	RH [%]
January	0,1	86	-0,2	94
February	-0,1	84	-0,1	91
March	2,0	82	2,1	87
April	5,6	76	5,7	81
May	10,9	72	10,8	77
June	15,0	72	14,1	78
July	16,4	73	15,4	79
August	16,3	75	15,3	80
September	13,3	79	12,3	85
October	9,6	83	8,9	90
November	5,1	84	4,4	92
December	1,8	86	1,3	93
Year-mean	8,0	79	7,5	86

Table 5: Long-term annual mean MC and corresponding amplitude for Danish positions – long-term values read in year 30 after modelling start time. Time span from modelling start to first time mean MC reaches a level of 17% corresponding to a ΔMC of 5%.

Position	Copen-hagen	Karup
Long-term annual MC mean [%]	18,3	21.3
Long-term annual MC amp. [%]	±0,5	±0,7
Time 0:0 to ΔMC=+5% [YY:MM]	04:00	01:10

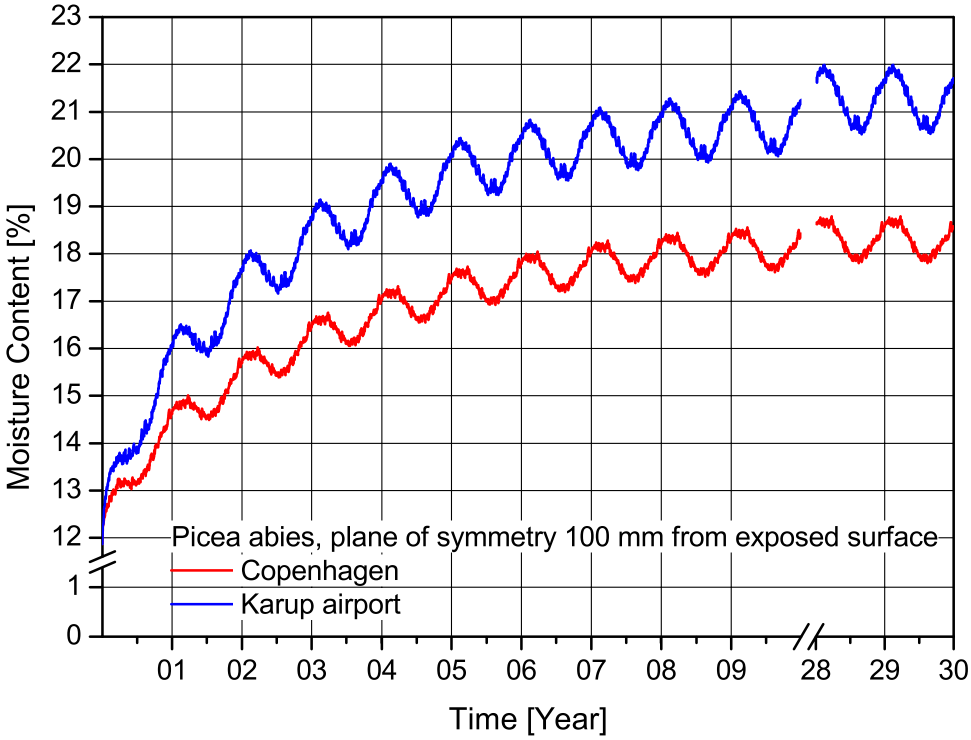

Figure 16: Development in mean moisture content of a 100 mm thick Picea abies member exposed one-sided to the two selected Danish climatological normal standards in a symmetrical one-dimensional model with transverse water vapour transport.

5.1.1 Copenhagen

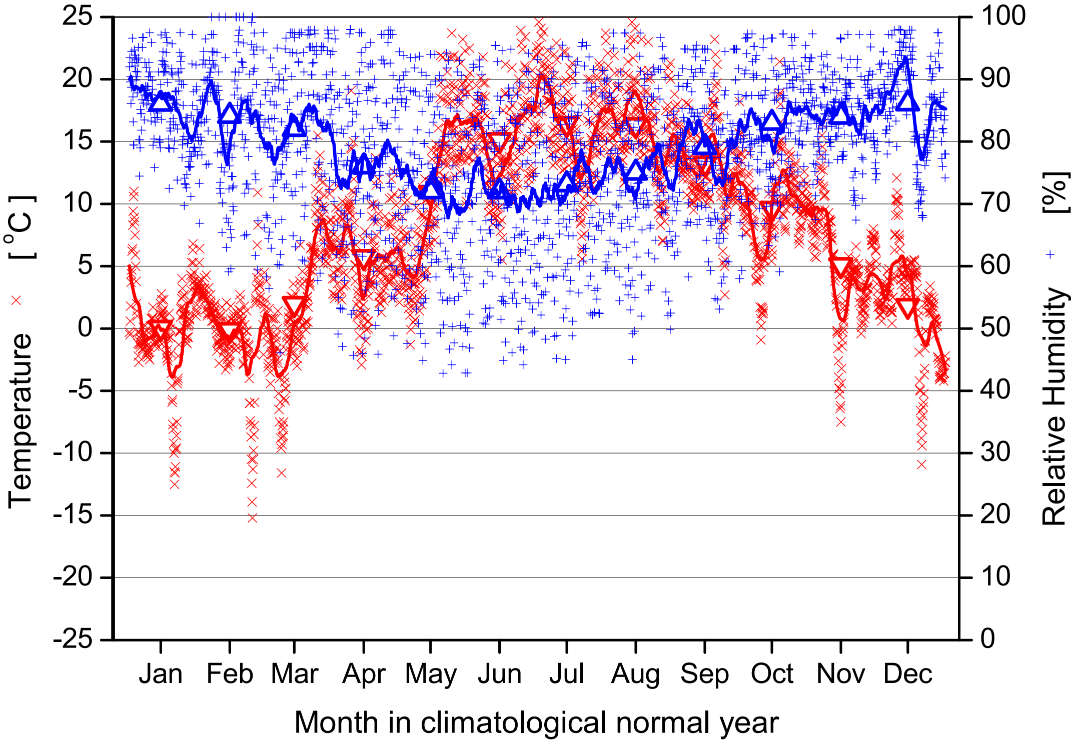

Figure 17: Copenhagen climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

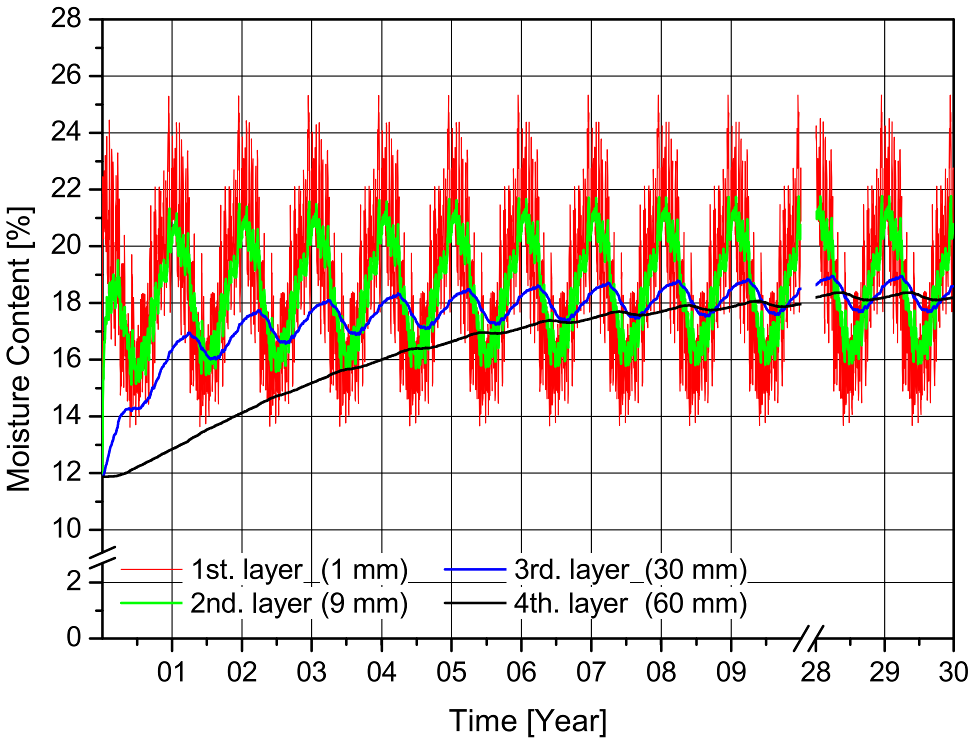

Figure 18: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Copenhagen climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.1.2 Karup

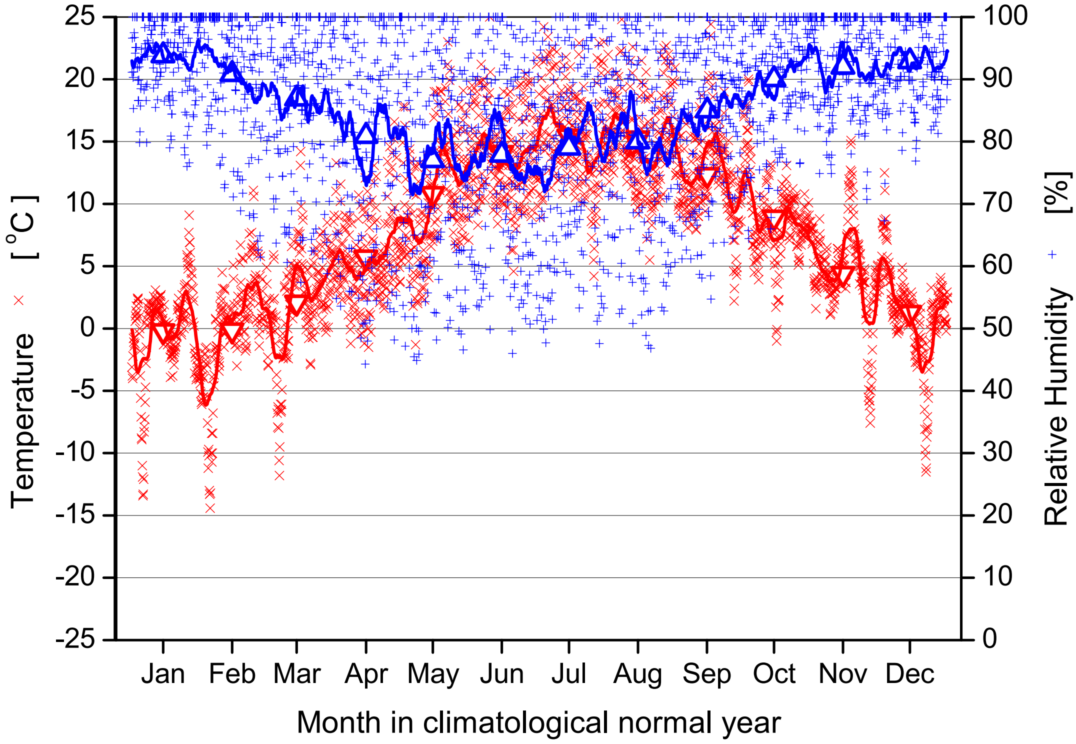

Figure 19: Karup climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

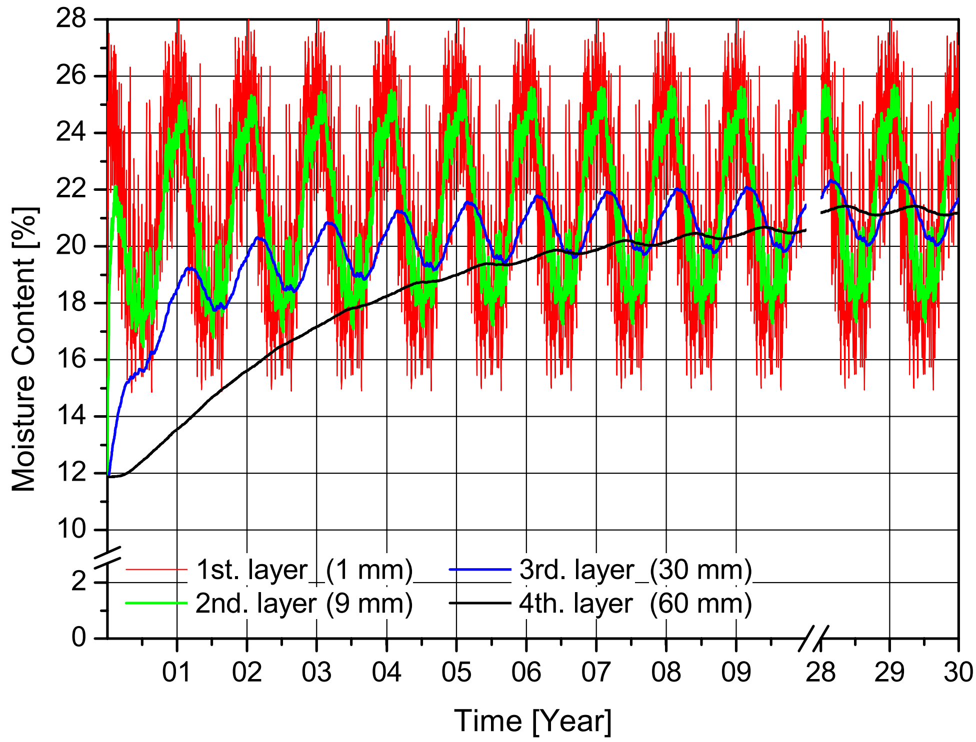

Figure 20: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Karup climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.2 Norway

Table 6: Summary of climatic standard normal for the modelled Norwegian positions. The mean values on a monthly basis for Oslo and Bergen are quoted from (WMO, 1996), note that the values for Oslo given in (Geving & Thue, 2002) are identical for temperature but consistently higher for the relative humidity. No WMO climatological standard normal is available for Lillehammer and Trondheim hence values from (Geving & Thue, 2002) are quoted and used as provisional standard normal.

Position	Oslo-Blindern		Bergen-Florida		Lille-hammer		Trond-heim	
WMO-No.	01492		01317					
Altitude Latitude Longitude	96 m 59.57 N 10.43 E		36 m 60.23 N 05.20 E		300 m 61.06 N 10.27 E		20 m 63.36 N 10.23 E	
	T [ºC]	RH [%]	T [ºC]	RH [%]	T [ºC]	RH [%]	T [ºC]	RH [%]
January	-4,3	81	1,5	78	-9,3	87	-3,3	78
February	-4,0	78	1,6	76	-8,0	83	-2,7	76
March	-0,2	72	3,3	73	-3,0	75	-0,1	75
April	4,5	65	5,9	72	2,2	71	3,0	76
May	10,8	64	10,5	72	8,8	64	8,7	74
June	15,2	65	13,5	76	13,5	68	12,0	78
July	16,4	67	14,5	77	14,7	74	13,2	79
August	15,2	72	14,4	78	13,3	78	12,7	81
September	10,8	76	11,5	79	8,5	82	9,0	83
October	6,3	80	8,7	78	3,6	84	5,6	82
November	0,7	80	4,7	78	-2,7	88	0,3	80
December	-3,1	81	2,6	79	-7,3	90	-2,0	79
Year-mean	5,7	73	7,7	76	2,9	79	4,7	78

Table 7: Long-term annual mean MC and corresponding amplitude for Norwegian positions – long-term values read in year 30 after modelling start time. Time span from modelling start to first time mean MC reaches a level of 17% corresponding to a ΔMC of 5%.

Position	Oslo-Blindern	Bergen-Florida	Lille-hammer	Trond-heim
Long-term annual MC mean [%]	16,55	17,6	18,4	18,3
Long-term annual MC amp. [%]	±0,4	±0,2	±0,6	±0,2
Time 0:0 to ΔMC=+5% [YY:MM]	∞	06:09	04:11	04:11

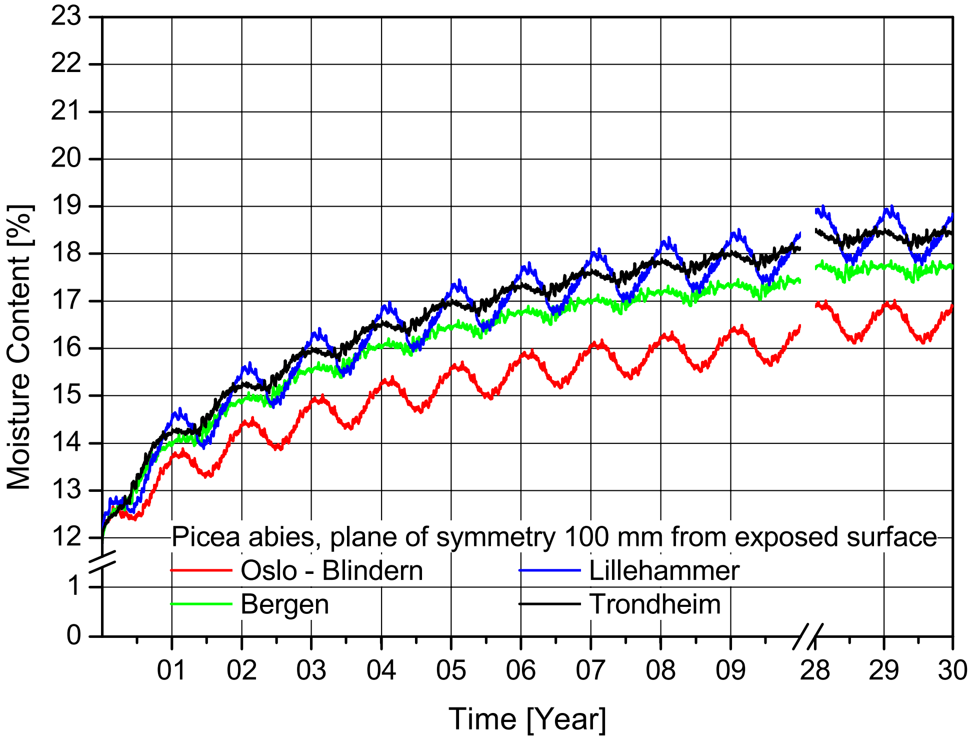

Figure 21: Development in mean moisture content of a 100 mm thick Picea abies member exposed one-sided to the four selected Norwegian climatological normal standards in a symmetrical one-dimensional model with transverse water vapour transport.

5.2.1 Oslo-Blindern

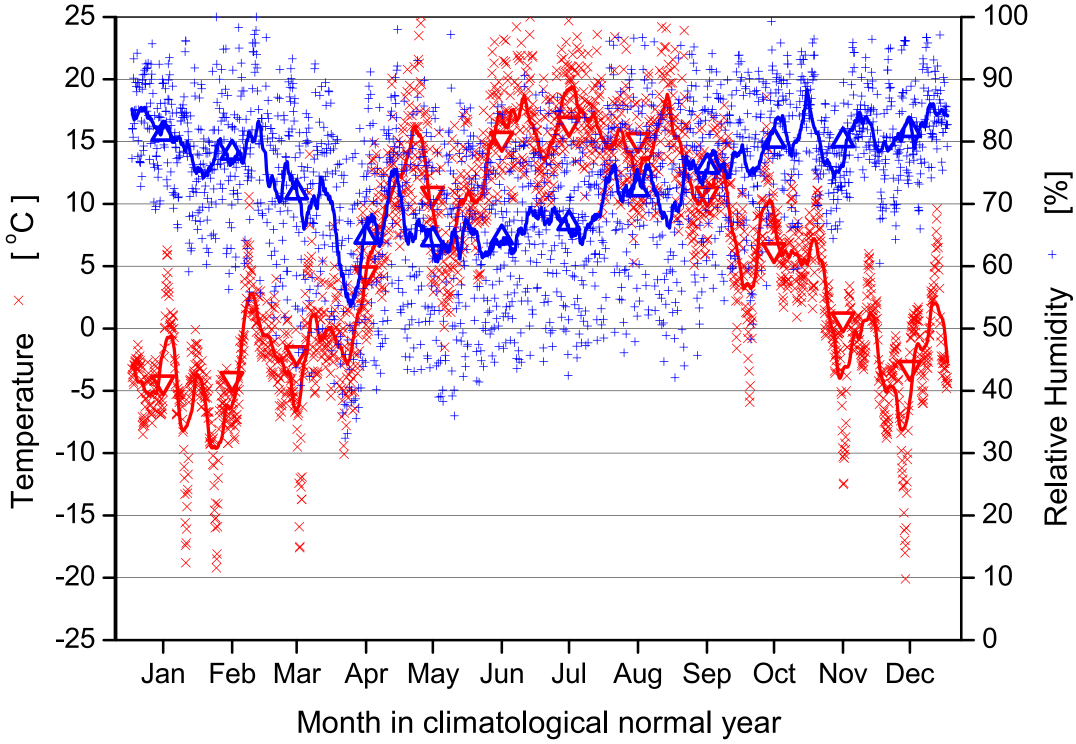

Figure 22: Oslo-Blindern climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

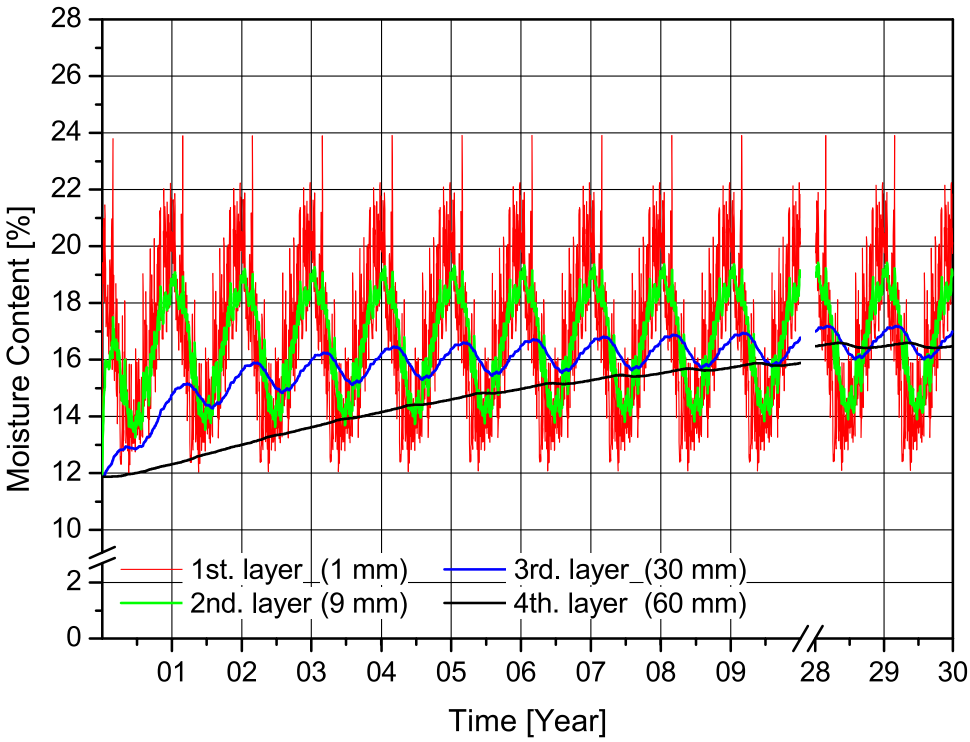

Figure 23: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Oslo-Blindern climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.2.2 *Bergen-Florida*

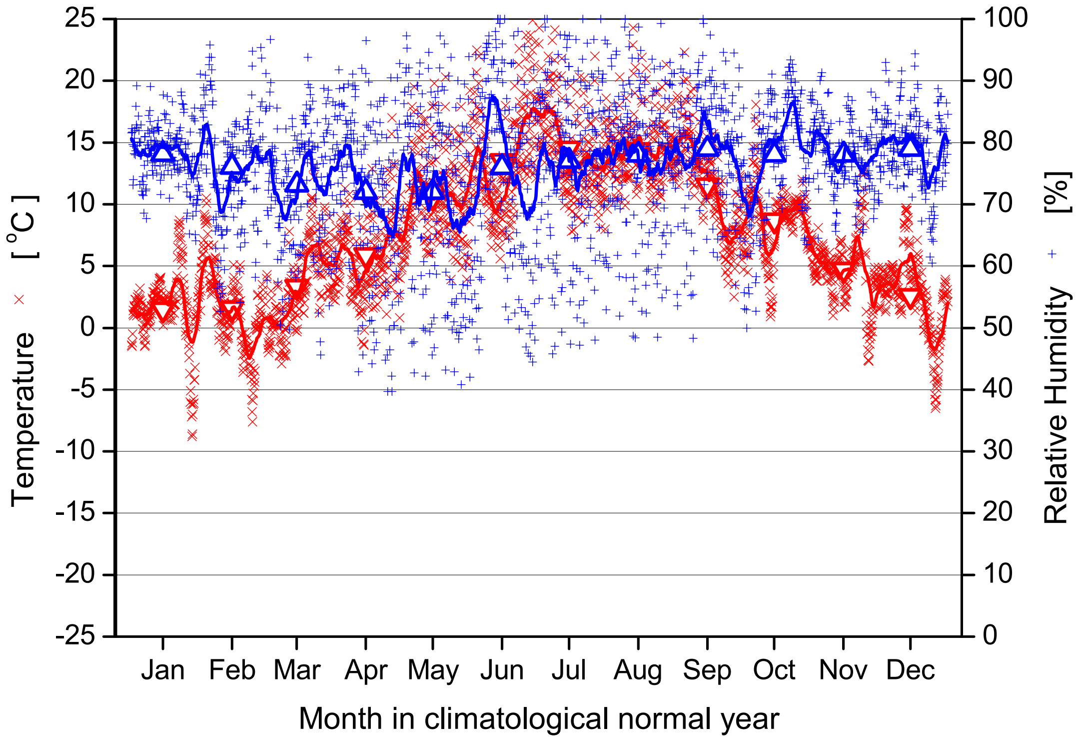

Figure 24: Bergen-Florida climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

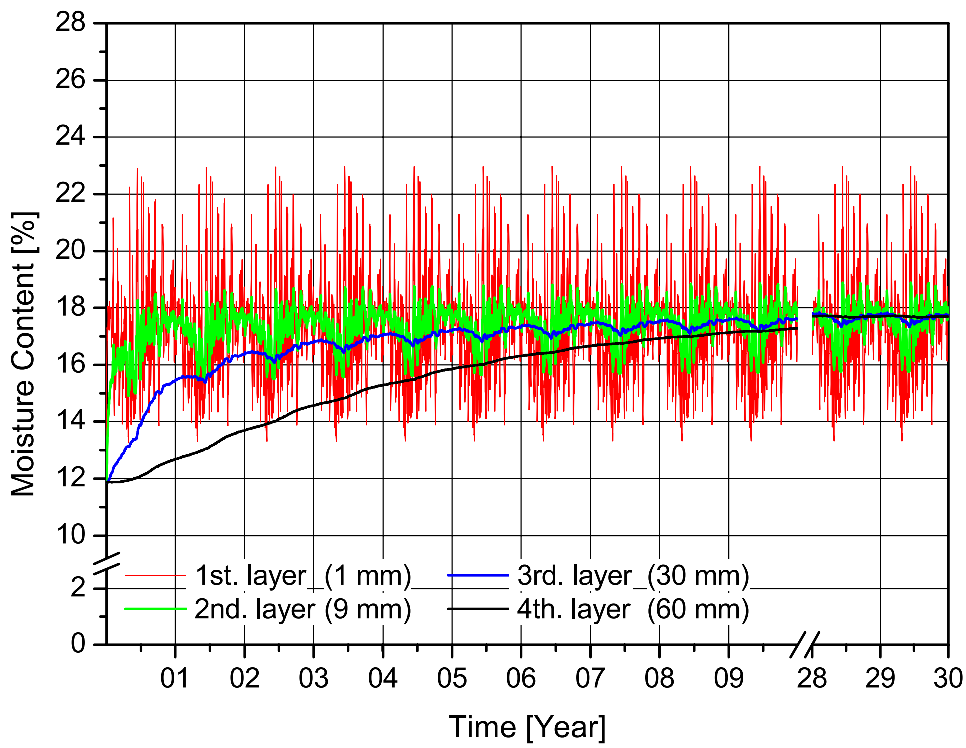

Figure 25: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Bergen-Florida climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.2.3 *Lillehammer*

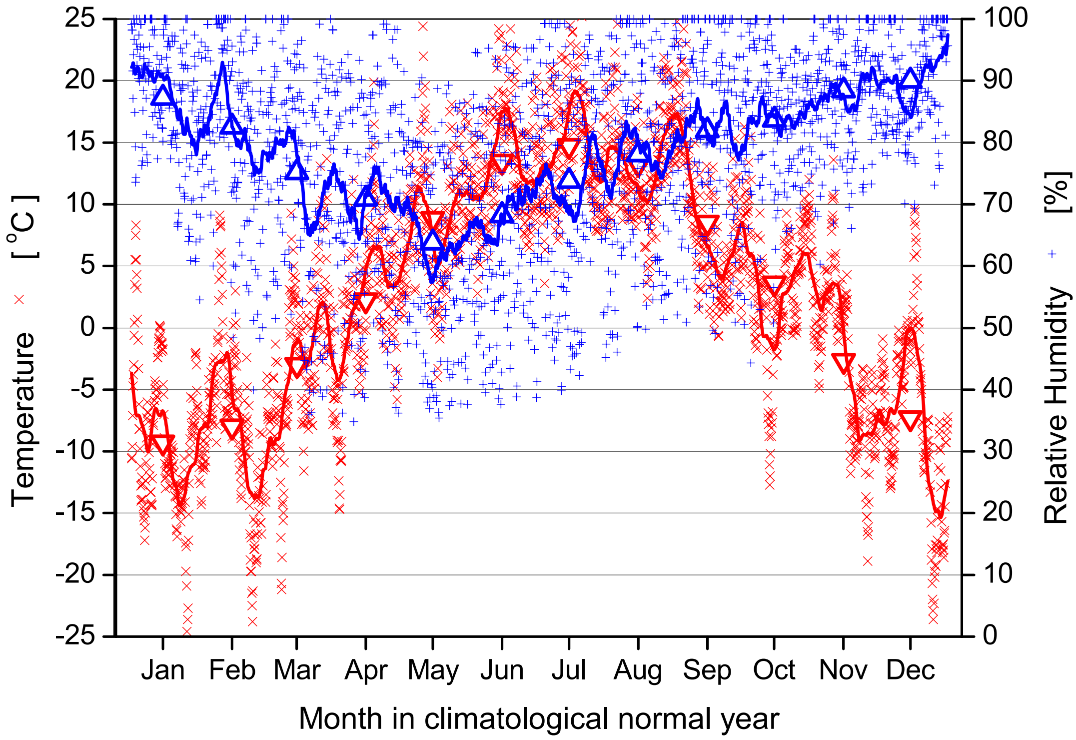

Figure 26: Lillehammer climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

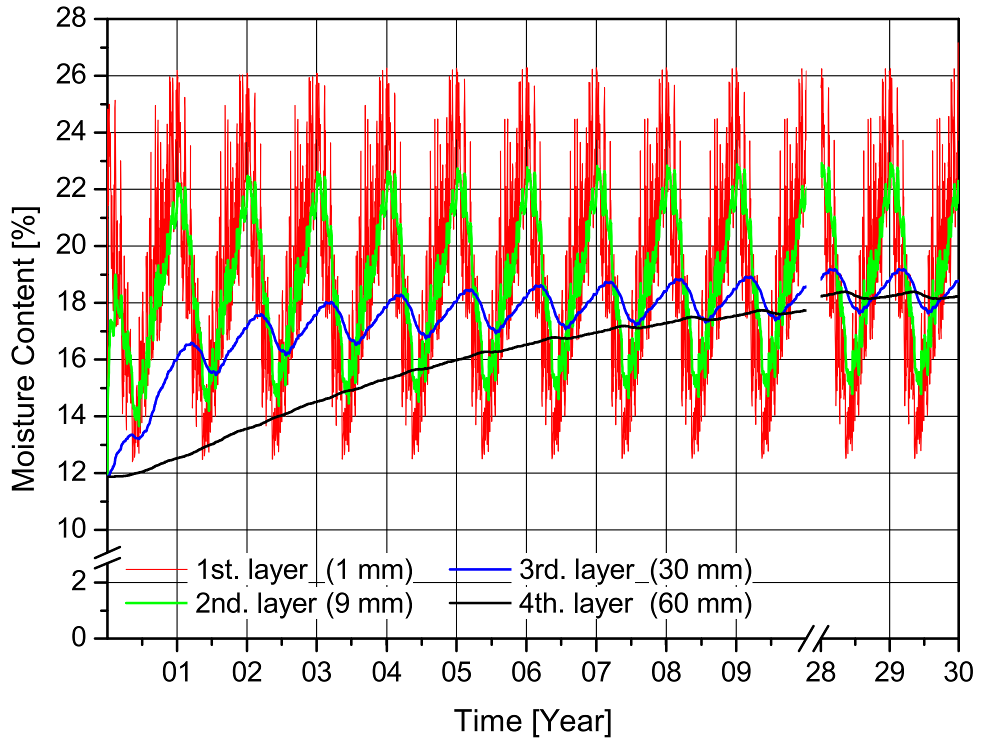

Figure 27: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Lillehammer climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.2.4 Trondheim

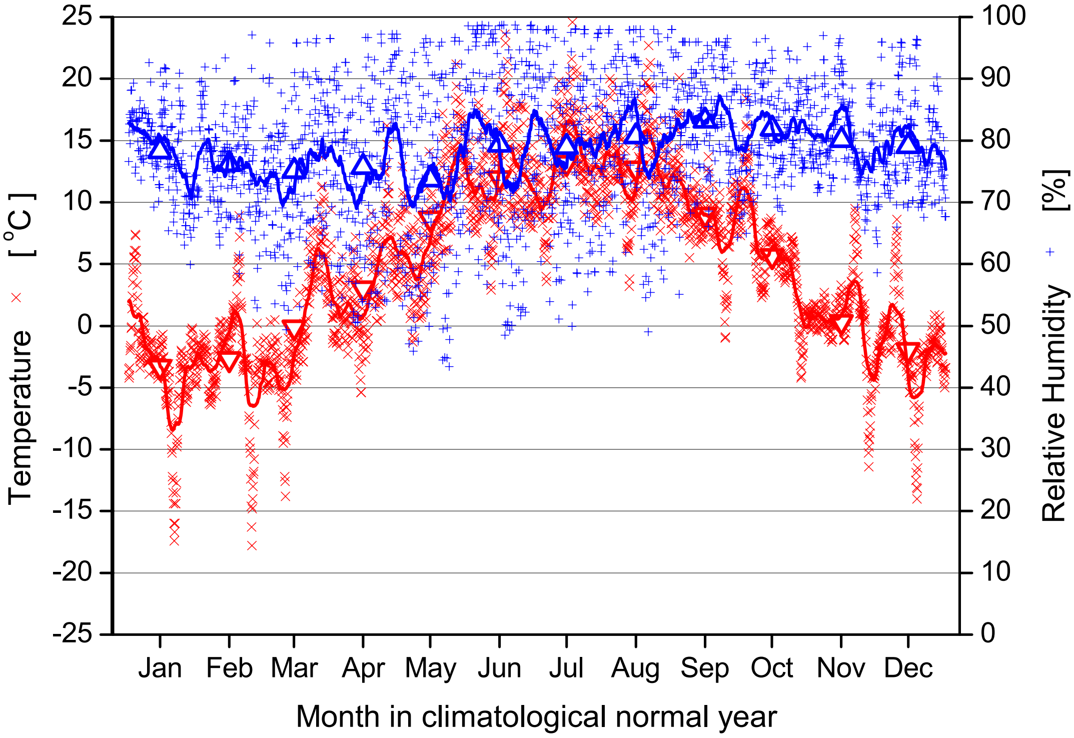

Figure 28: Trondheim climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

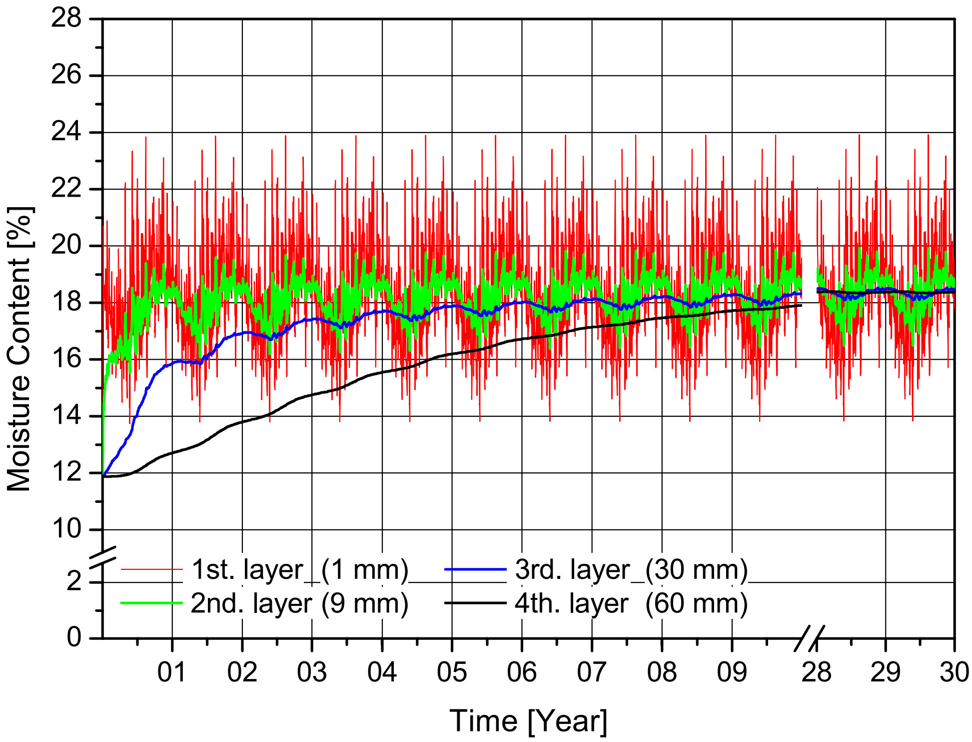

Figure 29: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Trondheim climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.3 Sweden

Table 8: Summary of climatic standard normal for the modelled Swedish positions. The mean values on a monthly basis for all Swedish positions are quoted from CLINO-data 1961-90 purchased from the Swedish Meterological and Hydrological Institute. The same data are given in (WMO, 1996) - except positions Umeå and Luleå. However in this latter reference, the relative humidity is given in vapour pressure, which – especially at low temperatures – can cause substantial error in the determination of relative humidity.

Position	Stock-holm		Karlstad		Jönköping		Gunnarn		Umeå		Luleå	
WMO-No.	02485		02418		02550		02128		02286		02186	
Altitude Latitude Longitude	5 m 59.34 N 18.06 E		55 m 59.22 N 13.28 E		232 m 57.46 N 14.05 E		283 m 64.58 N 17.42 E		10 m 63.5 N 20.2 E		16 m 65.3 N 22.1 E	
	T [ºC]	RH [%]	T [ºC]	RH [%]	T [ºC]	RH [%]	T [ºC]	RH [%]	T [ºC]	RH [%]	T [ºC]	RH [%]
January	-2,8	85	-4,6	86	-3,6	90	-12,9	83	-8,9	88	-10,6	85
February	-3,0	82	-4,7	85	-3,8	88	-10,4	82	-8,3	86	-10,0	84
March	0,1	76	-1,1	80	-0,9	83	-5,8	78	-3,9	83	-5,0	83
April	4,6	68	3,6	73	3,7	76	0,0	73	1,1	77	0,0	77
May	10,7	61	9,9	68	9,6	68	7,0	66	7,8	69	6,7	69
June	15,6	61	14,7	68	13,9	68	12,9	63	12,8	67	12,8	65
July	17,2	65	16,1	71	15,0	72	14,5	69	15,0	71	15,6	69
August	16,2	69	14,9	75	14,1	76	12,2	75	13,3	78	13,3	75
September	11,9	74	10,9	79	10,2	82	7,0	80	8,3	82	8,3	81
October	7,5	79	6,5	83	6,4	86	1,7	83	3,3	84	2,2	83
November	2,6	83	1,2	86	1,5	89	-5,6	86	-2,2	88	-3,9	86
December	-1,0	85	-2,9	86	-2,0	90	-11,1	84	-6,7	88	-8,9	86
Year-mean	6,6	74	5,4	78	5,3	81	0,8	77	2,6	80	1,7	79

Table 9: Long-term annual mean MC and corresponding amplitude for Swedish positions – long-term values read in year 30 after modelling start time. Time span from modelling start to first time mean MC reaches a level of 17% corresponding to a ΔMC of 5%.

Position	Stock-holm	Karlstad	Jönköping	Gunnarn	Umeå	Luleå
Long-term annual MC mean [%]	16,7	18,0	18,9	17,5	18,7	17,9
Long-term annual MC amp. [%]	±0,6	±0,5	±0,6	±0,5	±0,6	±0,5
Time 0:0 to ΔMC=+5% [YY:MM]	12:00	05:00	03:01	08:00	04:00	06:00

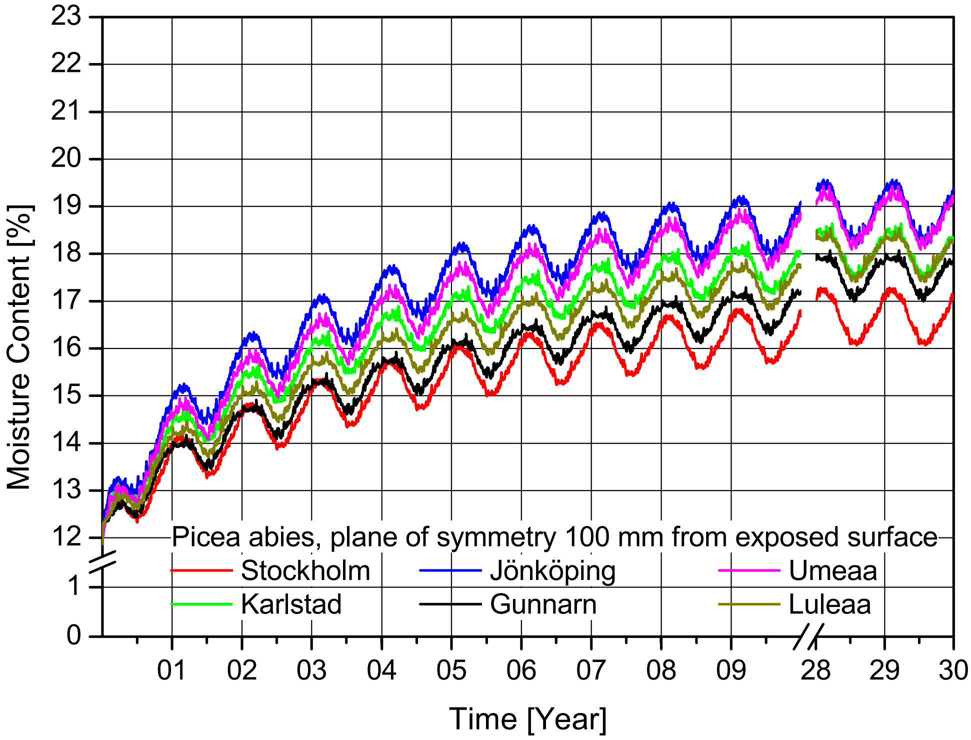

Figure 30: Development in mean moisture content of a 100 mm thick Picea abies member exposed one-sided to the six selected Swedish climatological normal standards in a symmetrical one-dimensional model with transverse water vapour transport.

5.3.1 Stockholm

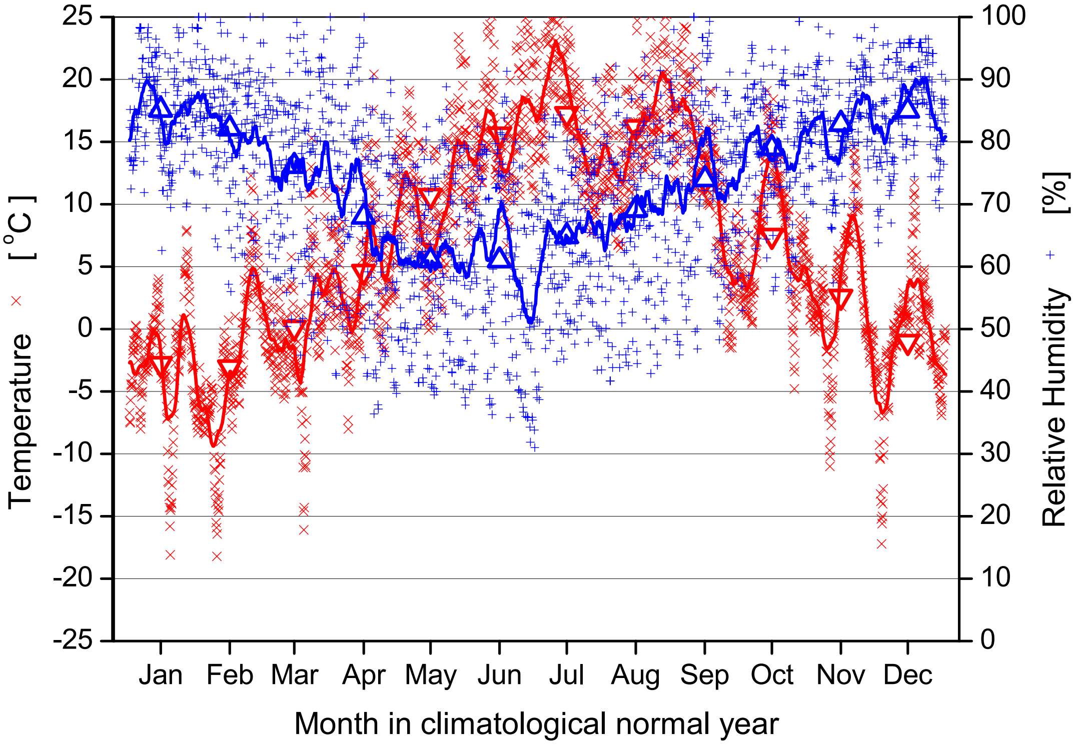

Figure 31: Stockholm climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

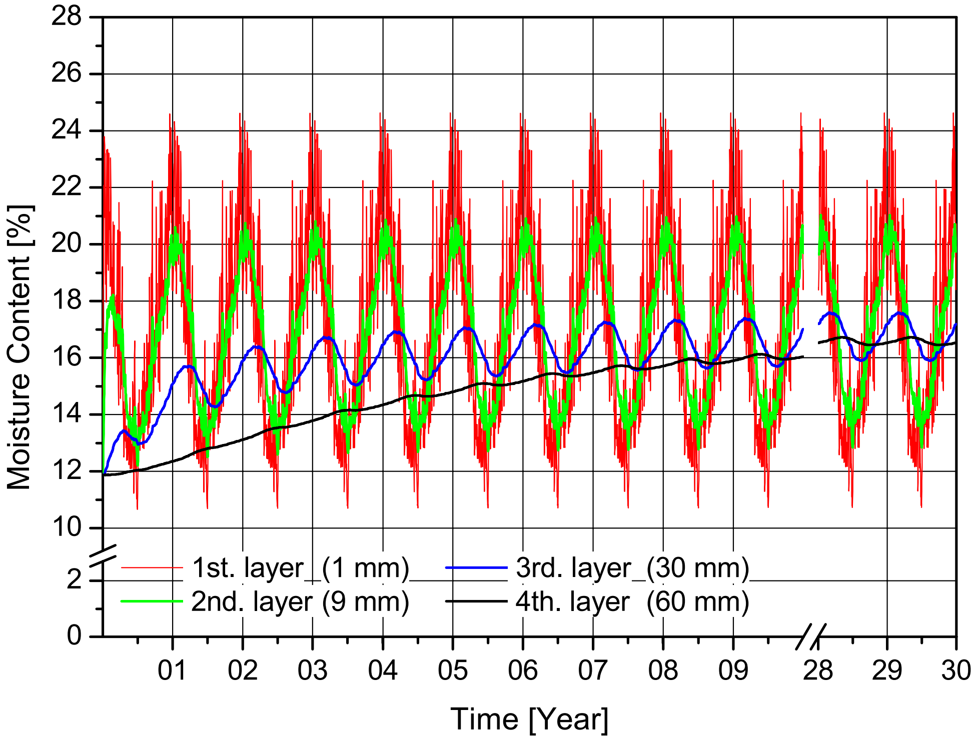

Figure 32: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Stockholm climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.3.2 *Karlstad*

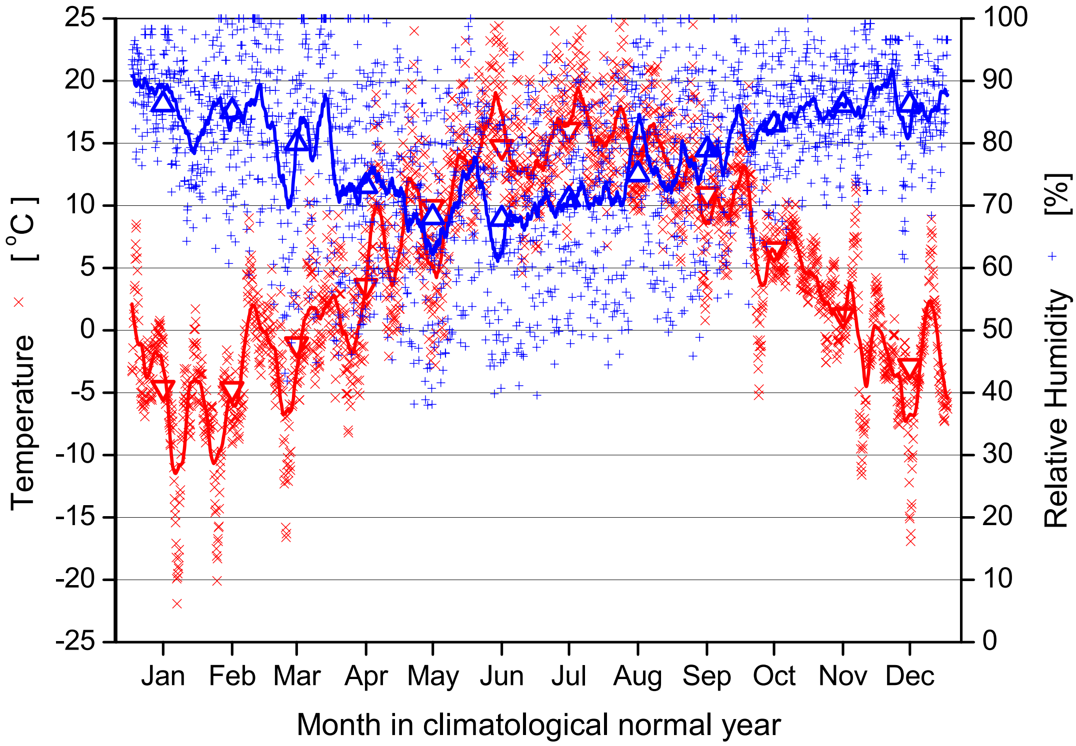

Figure 33: Karlstad climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

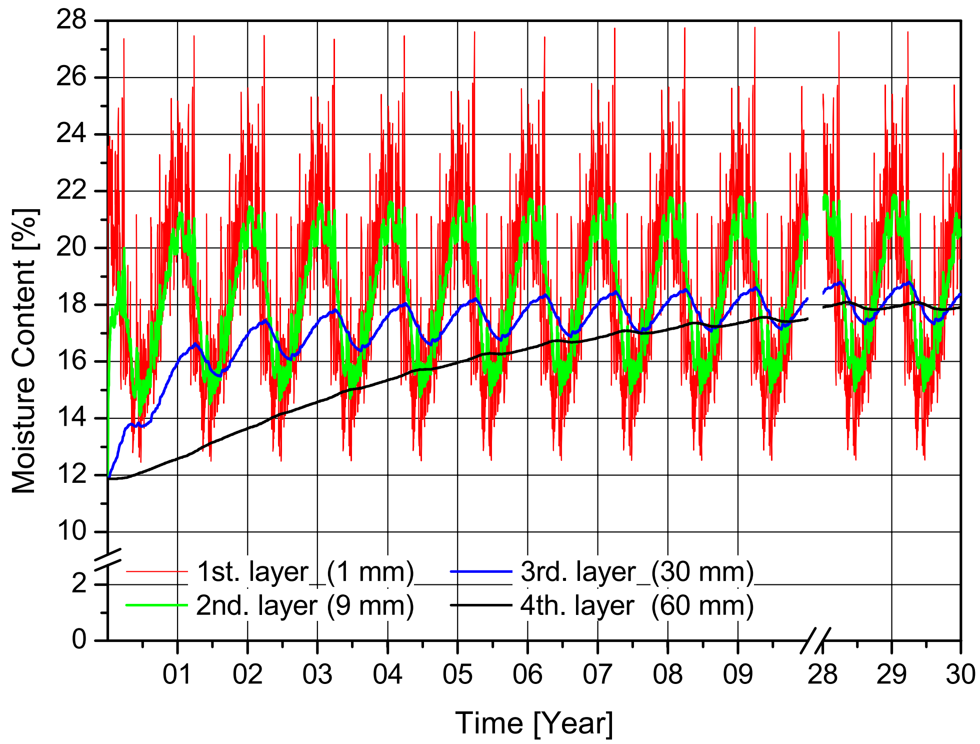

Figure 34: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Karlstad climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.3.3 *Jönköping*

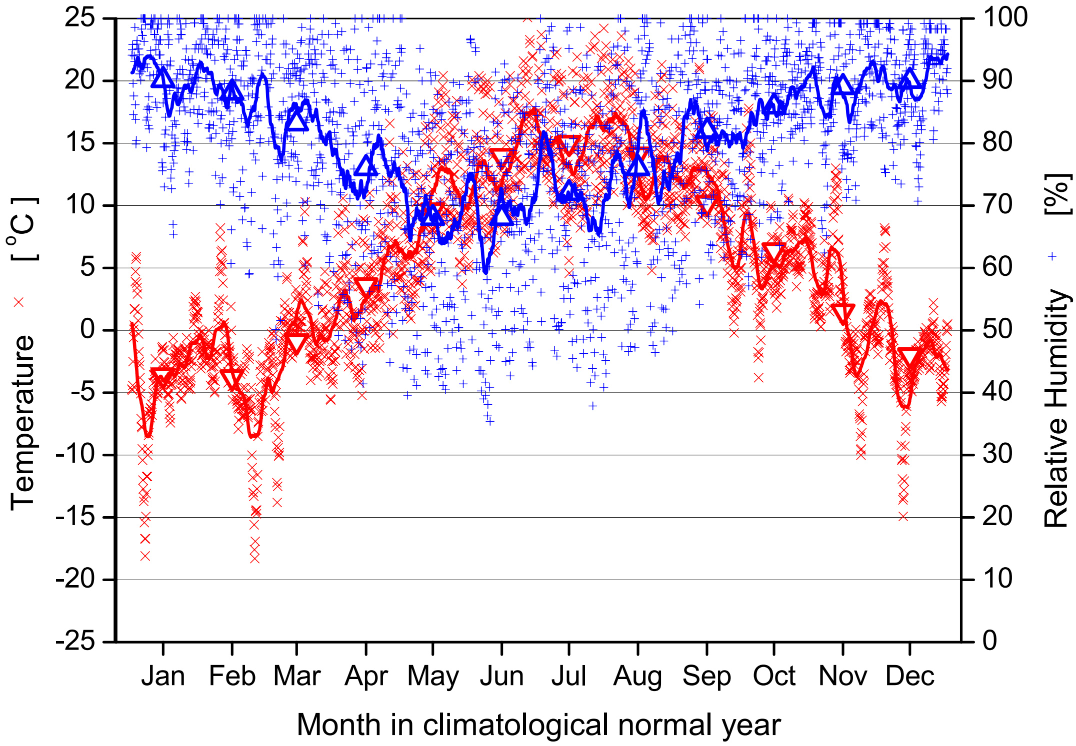

Figure 35: Jönköping climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

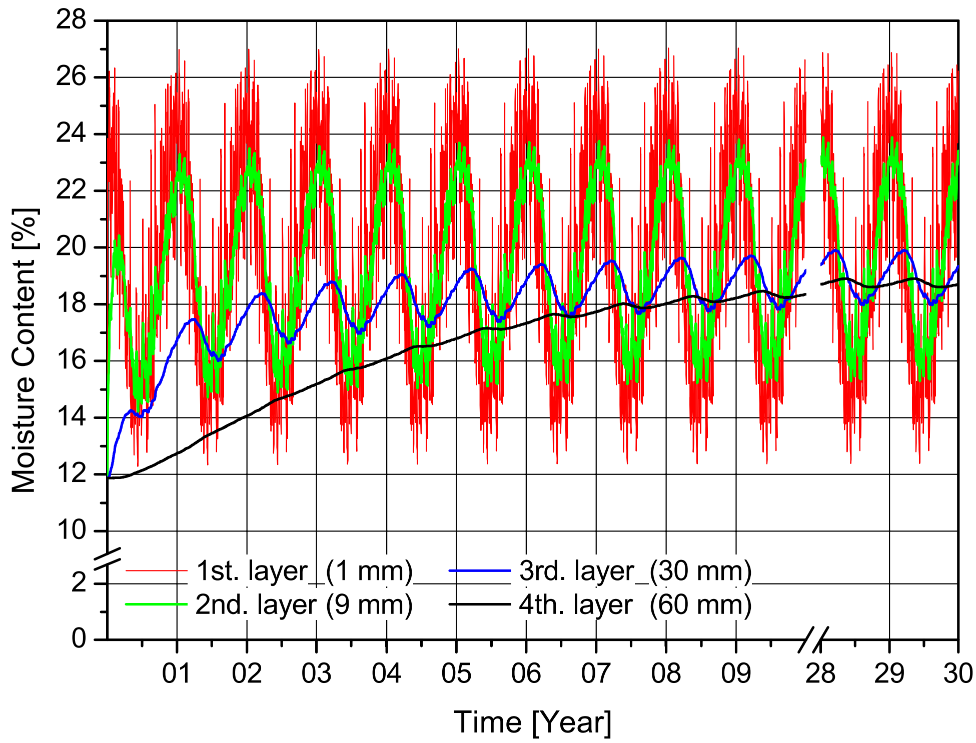

Figure 36: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Jönköping climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.3.4 Gunnarn

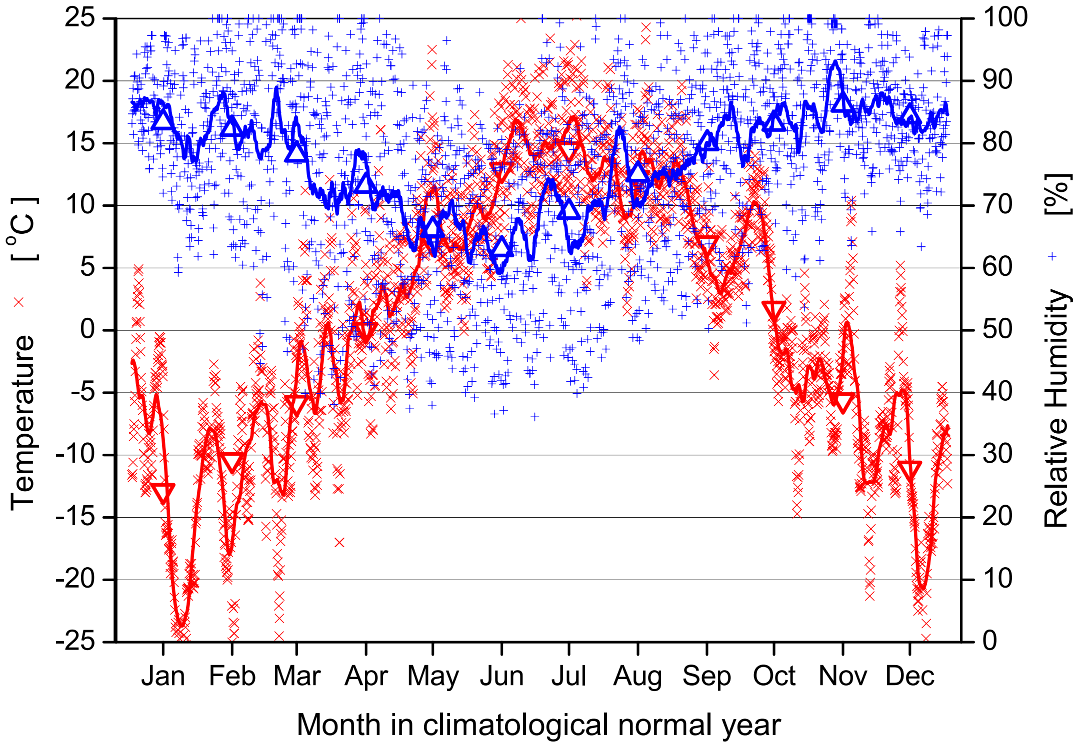

Figure 37: Gunnarn climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

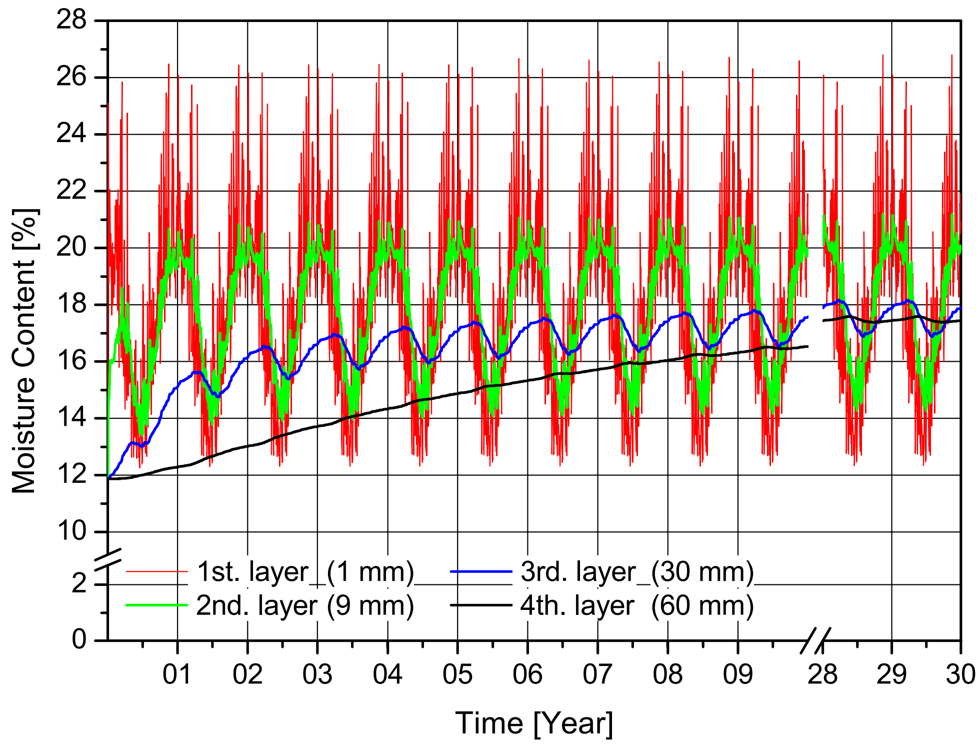

Figure 38: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Gunnarn climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.3.5 Umeå

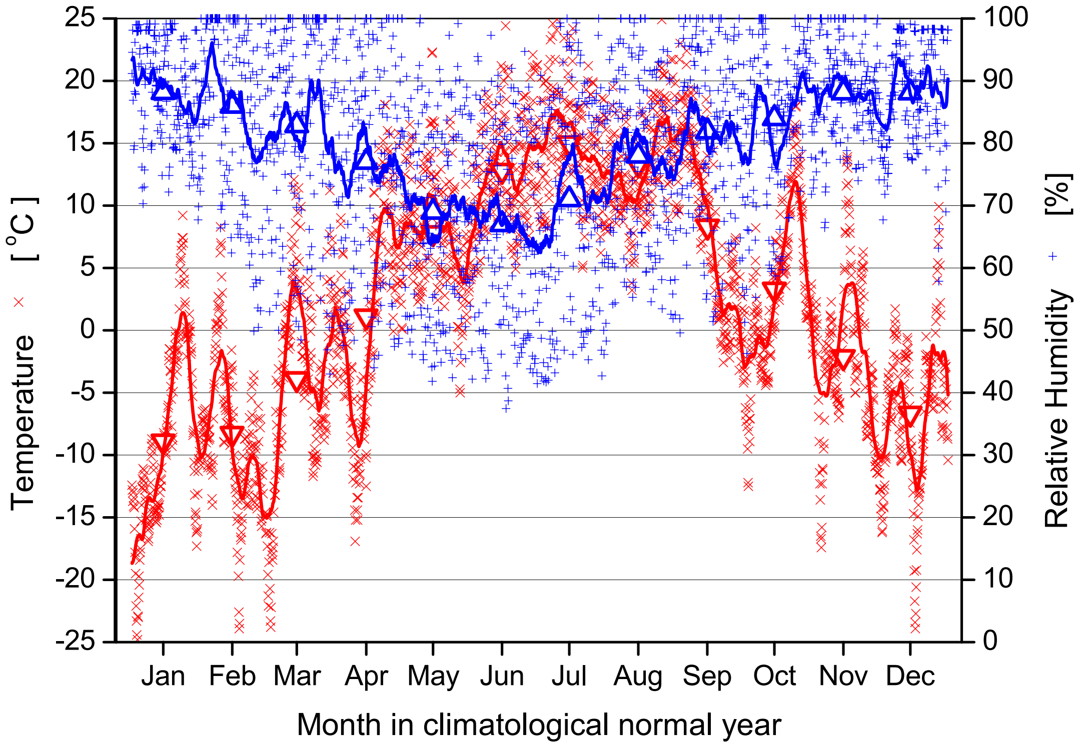

Figure 39: Umeå climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

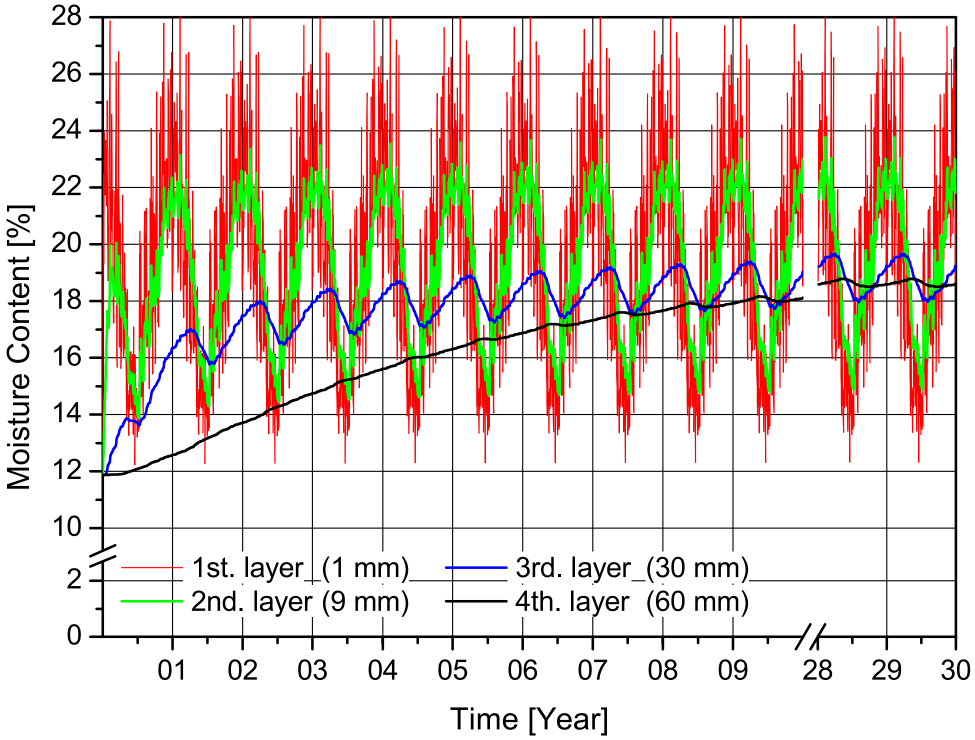

Figure 40: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Umeå climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.3.6 Luleå

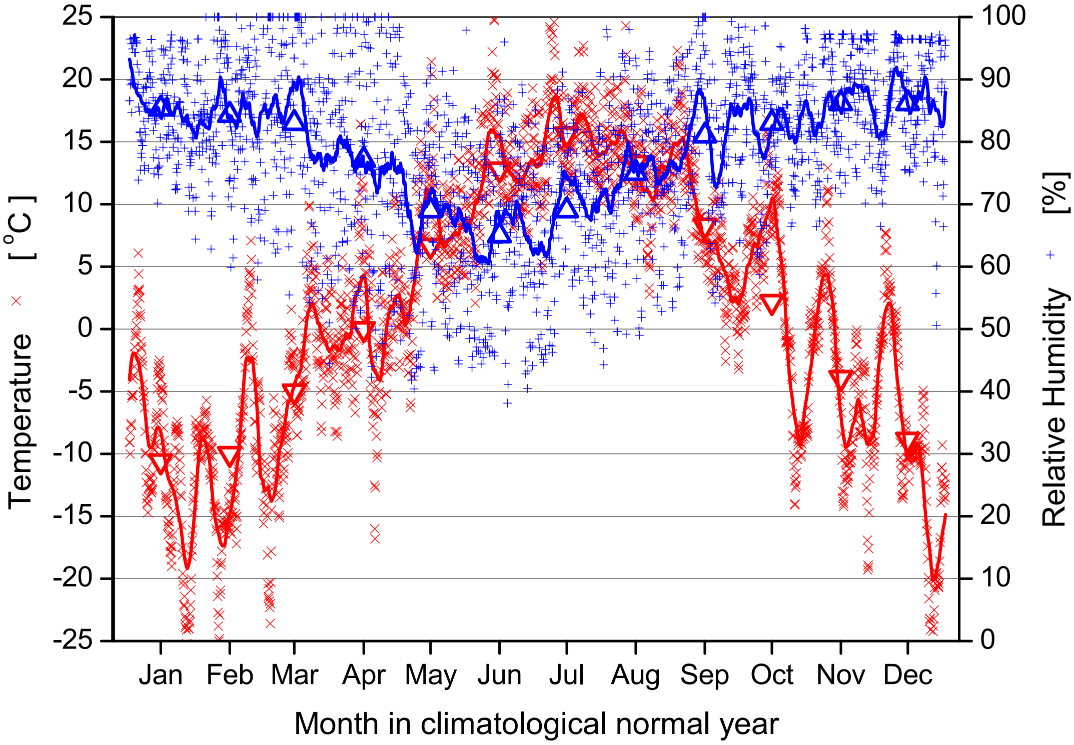

Figure 41: Luleå climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

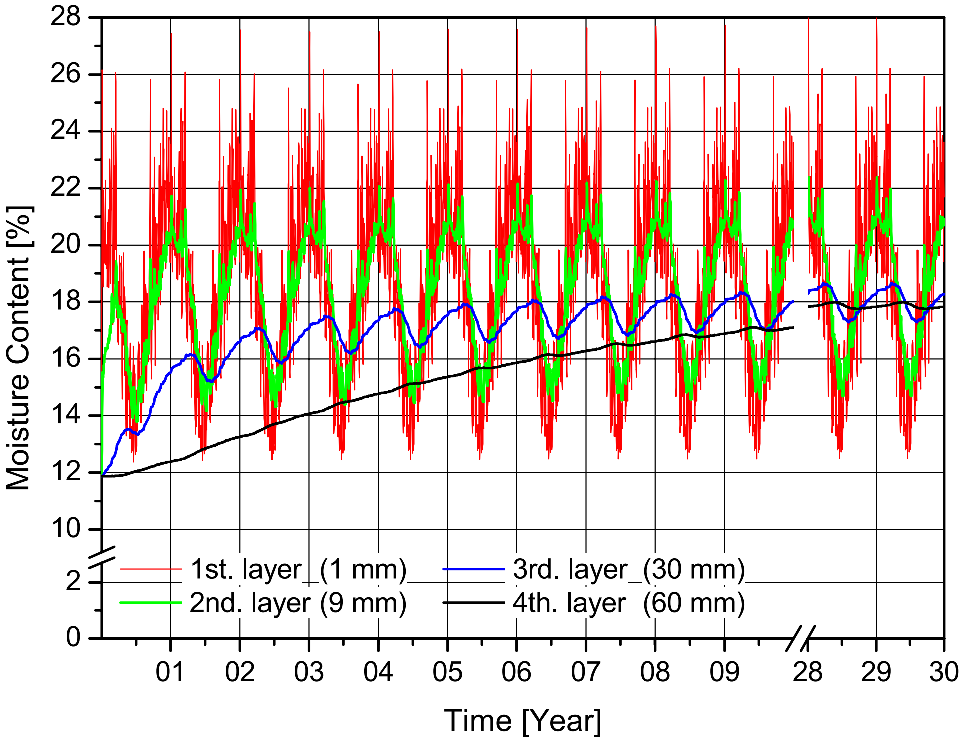

Figure 42: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Luleå climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.4 Finland

Table 10: Summary of climatic standard normal for the modelled Finnish positions. The mean values on a monthly basis for all Finnish positions are quoted from CLINO-data 1961-90 given in (Finnish Meteorological Institute, 1991). The same data are given in (WMO, 1996). However in this latter reference, the relative humidity is given in vapour pressure, which – especially at low temperatures – can cause substantial error in the determination of relative humidity.

Position	Helsinki-Vantaa		Oulu		Kuusamo	
WMO-No.	02974		02875		02869	
Altitude Latitude Longitude	56 m 60.19 N 24.58 E		15 m 64.56 N 25.22 E		263 m 65.58 N 29.11 E	
	T [ºC]	RH [%]	T [ºC]	RH [%]	T [ºC]	RH [%]
January	-6,9	88	-11,1	86	-14,2	86
February	-6,8	86	-10,4	85	-12,9	85
March	-2,9	82	-5,8	82	-8,2	82
April	2,9	74	0,5	74	-2,2	75
May	9,9	65	7,5	67	5,0	69
June	14,9	66	13,5	65	11,7	67
July	16,6	72	16,0	70	14,2	72
August	15,0	78	13,7	77	11,4	79
September	10,0	84	8,4	82	6,1	85
October	5,4	86	3,0	85	0,1	88
November	0,1	89	-3,1	88	-6,2	90
December	-4,1	89	-8,2	88	-11,5	87
Year-mean	4,5	80	2,0	79	-0,6	80

Table 11: Long-term annual mean MC and corresponding amplitude for Finnish positions – long-term values read in year 30 after modelling start time. Time span from modelling start to first time mean MC reaches a level of 17% corresponding to a ΔMC of 5%.

Position	Helsinki-Vantaa	Oulu	Kuusamo
Long-term annual MC mean [%]	18,6	18,3	18,8
Long-term annual MC amp. [%]	±0,7	±0,6	±0,6
Time 0:0 to ΔMC=+5% [YY:MM]	03:11	04:10	05:00

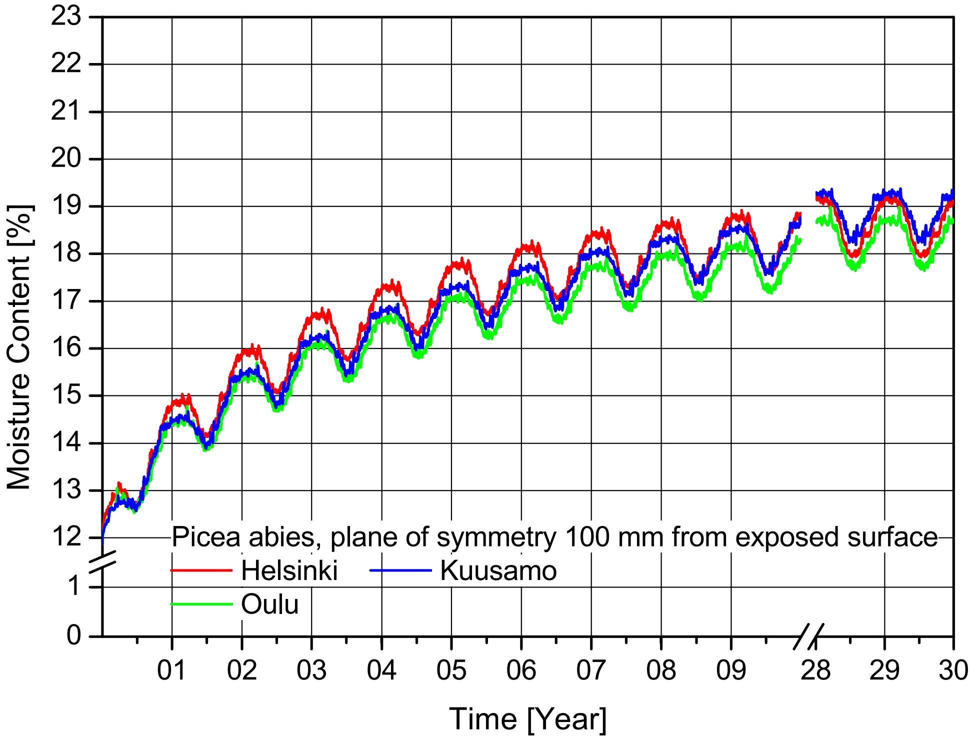

Figure 43: Development in mean moisture content of a 100 mm thick Picea abies member exposed one-sided to the three selected Finnish climatological normal standards in a symmetrical one-dimensional model with transverse water vapour transport.

5.4.1 Helsinki-Vantaa

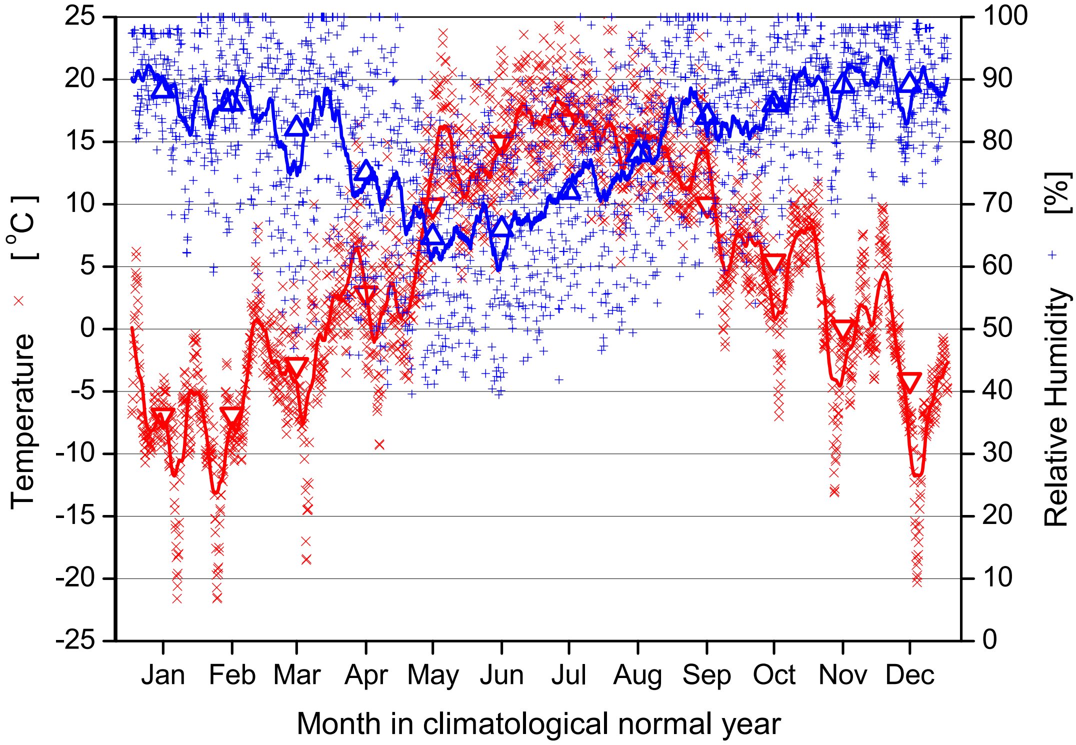

Figure 44: Helsinki-Vantaa climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

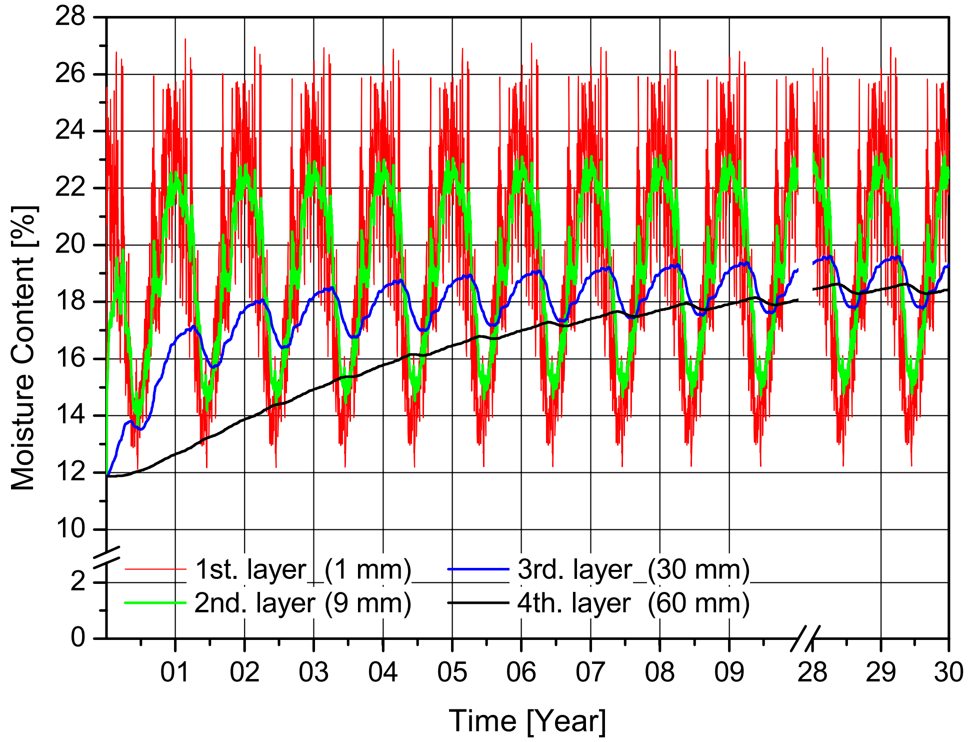

Figure 45: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Helsinki-Vantaa climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.4.2 Oulu

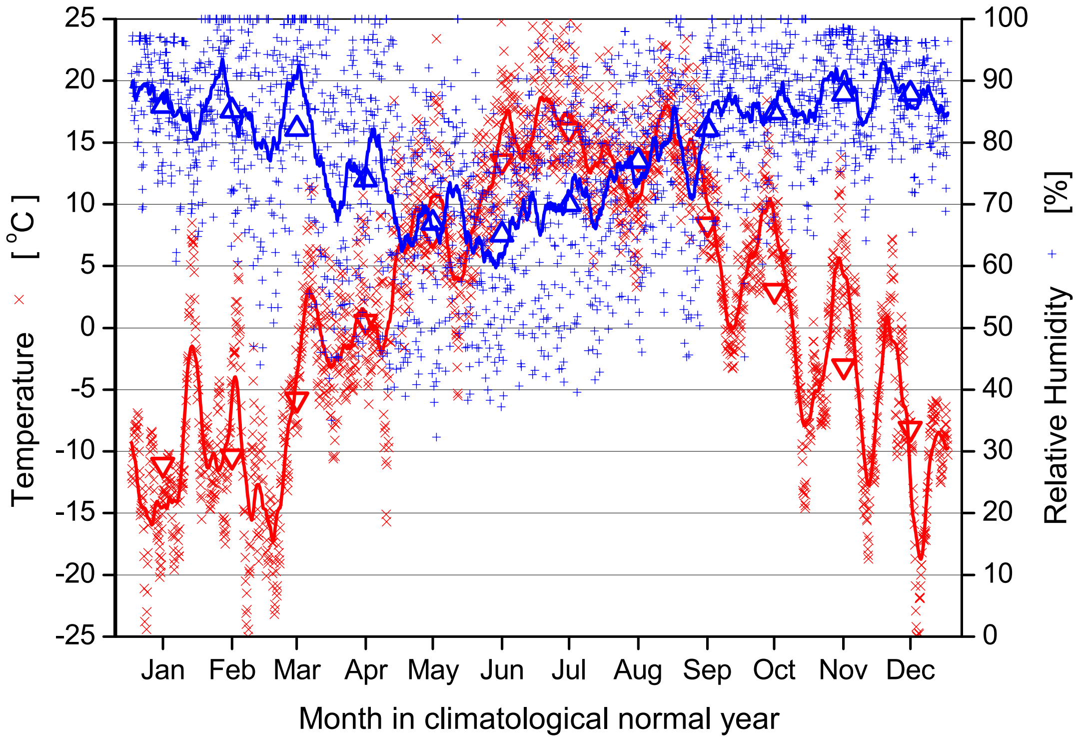

Figure 46: Oulu climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

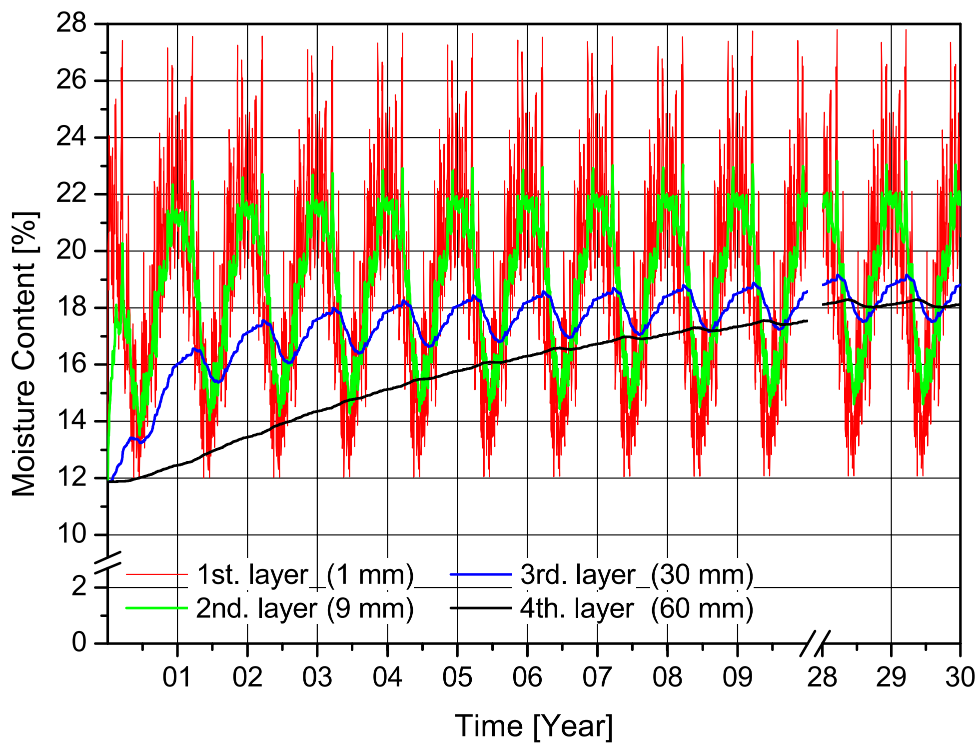

Figure 47: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Oulu climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

5.4.3 Kuusamo

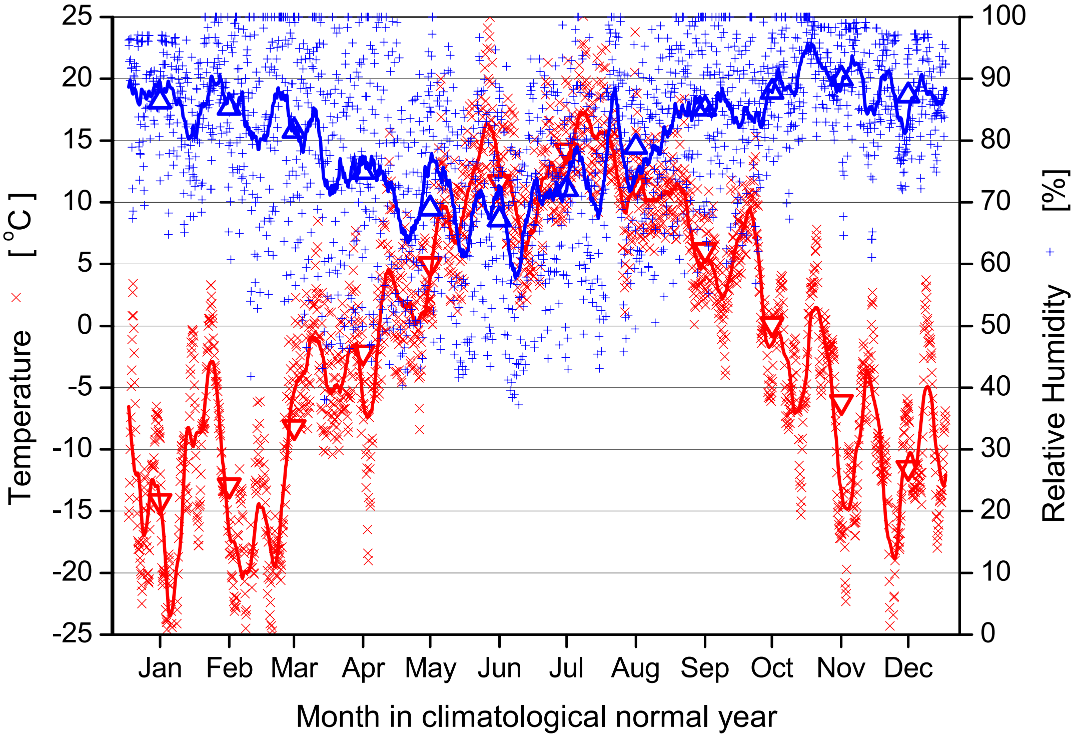

Figure 48: Kuusamo climatological normal standard. Data sets are shown in 4-hour intervals, running weekly average curves and monthly mean values are given. The modelling uses data sets given in one-hour intervals.

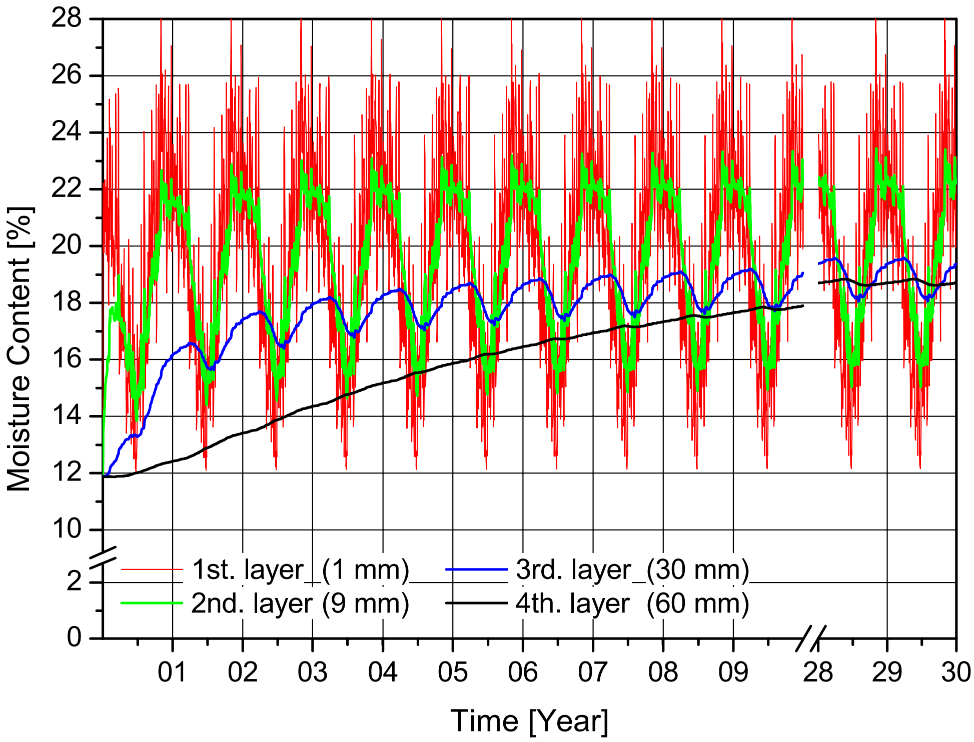

Figure 49: Development in MC in four layers of a 100 mm thick Picea abies member exposed one-sided to the Kuusamo climatological normal standard in a symmetrical one-dimensional model with transverse water vapour transport.

6 Discussion

The parameter study employed shows that the of shape the water vapour permeability function, $\delta_p(RH)$, to a high degree determines the long term-mean of the transient moisture content. The effect is that the mean level is biased towards the moist side. This finding explains the relatively high long-term mean TMC determined at different Nordic locations in the catalogue part of the investigation. The amplitude of the TMC is found to be relatively small, a result explained by the phase lag between the annual recurring moisture load history and the delayed moisture content response of the loaded members. Figure 50 shows the extreme cases observed at all investigated Nordic climates for the investigated geometry.

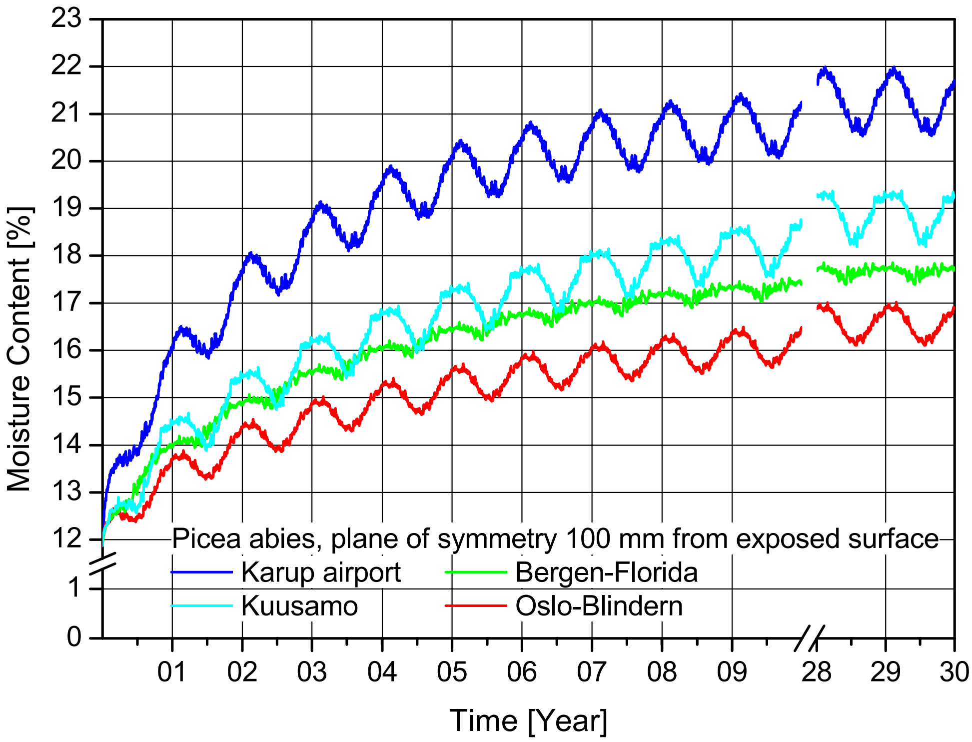

Figure 50: Development in mean moisture content of a 100 mm thick Picea abies member exposed one-sided to the four selected Nordic climatological normal standards in a symmetrical one-dimensional model with transverse water vapour transport.

7 Concluding remarks

The numerical studies laid forward in this investigation shows one new discovery, namely that the annual mean level long-term moisture content for timber elements with medium size or bigger cross-sections at outdoor covered conditions is highly influenced by the shape of the water vapour permeability relation.

This finding and the method applied form a theoretical basis for experimental model verification. When such model verification/calibration has been employed, it will be possible based on the relatively refined models used in the present investigation to set up relatively simple relations for determining the long-term moisture content for wood members as function of moisture load history and member thickness.

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Appendix 1 – Summary of MATCH output file - settings

```
MATCH Output File
MATCH ver. WinMATCH , rev. 041202.  User: COC
Calculations based on input file
D:\PARKERINGSHUS I TRÆ\SCANDINAVIAN CLIMATE\MATCH\GEN NORDIC
CLIMATES 100 mm\Copenhagen-corr-csn-30aar.in

100 mm 4 layers incl. hys and correct diffusion
```

INDOOR CLIMATE:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temp.(°C)	0.1	-0.1	2.0	5.6	10.9	15.0	16.4	16.3	13.3	9.6	5.1	1.8
RH (%)	86.0	84.0	82.0	76.0	72.0	72.0	73.0	75.0	79.0	83.0	84.0	86.0

[Indoor climate is given as month mean values for outdoor climate – but has no practical implications as the member is modelled with a symmetry boundary condition (NO HEAT OR MOISTURE FLUX) at the boundary to the "indoor climate"].

```
OUTDOOR CLIMATE:
Weather File:
C:\Program Files\MATCH16\ref\COPEHAGEN-CORR-CSN.REF

Shadingfile:
TOTALSKYGGE
```

[The shading file is constructed so as to secure that no direct sun light induced heating of the member is present].

```
Absorptance : 0.00   Emittance : 0.00   Ground Refl.: 0.00
Tilt Angle  :  0.0   Azimuth   :    0
Albedo      : 0.00   Latitude  : 56.0

MATERIALS:
Solidwood - Picea abies CORRECTSolidwood
Thickness:          1.0      9.0     30.0     60.0     mm
Dry density:        400      400      400      400     kg/m3
u-Initial:        11.87    11.87    11.87    11.87     weight-%

Interlayer Resistances:
Thermal       0.00     0.00     0.00     0.00     0.00 m²K/W
Diffusion     0.00     0.00     0.00     0.00     0.00 GPam²s/kg

Transition layer:
Thermal Resistance:               50  m²K/W
Diffusion Resistance:           5000  GPam²s/kg
```

[The transition layer models a symmetry boundary condition (NO HEAT OR MOISTURE FLUX) at the boundary to the "indoor climate"].

```
Period of Calculation:  JAN  1  to  DEC 31, Year 30

Absorption, Desorption, Hysteresis : H
Consider Latent Heat Transfer :      N
Consider Liquid Moisture Flow :      N
Time Step in Hours :                 1
```

Appendix 2 – Layer subdivision in MATCH

Matno	Delx	GridPointLoc.	u-initial	RH-initial
1	0.00002	0.01	0.11874	0.62700
1	0.00003	1.00	0.11874	0.62700
1	0.00006	1.00	0.11874	0.62700
1	0.00013	1.00	0.11874	0.62700
1	0.00026	1.00	0.11874	0.62700
1	0.00026	1.00	0.11874	0.62700
1	0.00013	1.00	0.11874	0.62700
1	0.00006	1.00	0.11874	0.62700
1	0.00003	1.00	0.11874	0.62700
1	0.00002	1.00	0.11874	0.62700
2	0.00015	1.00	0.11874	0.62700
2	0.00029	1.00	0.11874	0.62700
2	0.00058	1.00	0.11874	0.62700
2	0.00116	1.00	0.11874	0.62700
2	0.00232	1.00	0.11874	0.62700
2	0.00232	1.00	0.11874	0.62700
2	0.00116	1.00	0.11874	0.62700
2	0.00058	1.00	0.11874	0.62700
2	0.00029	1.00	0.11874	0.62700
2	0.00015	1.00	0.11874	0.62700
3	0.00048	1.00	0.11874	0.62700
3	0.00097	1.00	0.11874	0.62700
3	0.00194	1.00	0.11874	0.62700
3	0.00387	1.00	0.11874	0.62700
3	0.00774	1.00	0.11874	0.62700
3	0.00774	1.00	0.11874	0.62700
3	0.00387	1.00	0.11874	0.62700
3	0.00194	1.00	0.11874	0.62700
3	0.00097	1.00	0.11874	0.62700
3	0.00048	1.00	0.11874	0.62700
4	0.00097	1.00	0.11874	0.62700
4	0.00194	1.00	0.11874	0.62700
4	0.00387	1.00	0.11874	0.62700
4	0.00774	1.00	0.11874	0.62700
4	0.01548	1.00	0.11874	0.62700
4	0.01548	1.00	0.11874	0.62700
4	0.00774	1.00	0.11874	0.62700
4	0.00387	1.00	0.11874	0.62700
4	0.00194	1.00	0.11874	0.62700
4	0.00097	1.00	0.11874	0.62700

Appendix 3 – Material property settings in MATCH

These are the settings for the material properties used in the present report; please refer to the MATCH help, and the explanations to the abbreviations given below.

```
*Solidwood - Picea abies CORRECT
1         0.01      0.77      0.9
400.0     2500.0    7.0       0.10      0.17      0.21      0.0
DELTAL_X  0.0000    0.2017      0.4034      0.5042      0.6050
0.6555      0.7059      0.7563      0.8067      0.8571      0.9076
0.9496      1.00000.0 *
DELTAL_Y  1.145E-12 1.265E-12   1.463E-12   1.754E-12   2.396E-12
2.965E-12   3.810E-12   5.065E-12   6.928E-12   9.693E-12   1.380E-
11   1.870E-11   2.698E-11
DELTAH_X  0.2942 *
DELTAH_Y  1.5E-11
ABSORP_X  0.0       0.205     0.440     0.6525    0.8585    0.955
0.986 *
ABSORP_Y  0.0       0.053     0.0875    0.123     0.1805    0.2495
0.306
DESORP_X  0.0       0.202     0.452     0.6523    0.8015    0.899
0.9535 *
DESORP_Y  0.0       0.063     0.111     0.1507    0.1995    0.244
0.2775
0.350     0.309     1.760
HYDCND_X  0.309 *
HYDCND_Y  1.0E-50
SUCABS_X  -10.0     14.786 *
SUCABS_Y  0.309     0.2951
SUCDRY_X  -10.0     14.786 *
SUCDRY_Y  1.76      0.2938
 Solidwood REFINED, 400 kg/m3, k=0.10 W/mK, d=1.145E-12 / 2.27E-11
kg/msPa
Vap.Perm:
Sorption: KKH->LA (Spruce).
HydrCond: Dummy values (liquid flow not active)
Suction : Dummy values
COC 130503
```

```
*Solidwood - Picea abies RIGHT SHIFT
1         0.01      0.77      0.9
400.0     2500.0    7.0       0.10      0.17      0.21      0.0
DELTAL_X  0.0000      0.2017      0.4034      0.5042      0.6050
0.6555      0.7059      0.7563      0.8067      0.8571      0.9076
0.9496      1.0000 *
DELTAL_Y  1.145E-12   1.205E-12   1.265E-12   1.463E-12   1.754E-12
2.396E-12   2.965E-12   3.810E-12   5.065E-12   6.928E-12   9.693E-
12   1.380E-11   1.870E-11
DELTAH_X  0.2942 *
DELTAH_Y  1.5E-11
ABSORP_X  0.0       0.205     0.440     0.6525    0.8585    0.955
0.986 *
ABSORP_Y  0.0       0.053     0.0875    0.123     0.1805    0.2495
0.306
DESORP_X  0.0       0.202     0.452     0.6523    0.8015    0.899
0.9535 *
DESORP_Y  0.0       0.063     0.111     0.1507    0.1995    0.244
0.2775
0.350     0.309     1.760
```

```
HYDCND_X  0.309 *
HYDCND_Y  1.0E-50
SUCABS_X  -10.0     14.786 *
SUCABS_Y  0.309     0.2951
SUCDRY_X  -10.0     14.786 *
SUCDRY_Y  1.76      0.2938
 Solidwood RIGHT SHIFT, 400 kg/m3, k=0.10 W/mK, d=1.145E-12 /
1.87E-11 kg/msPa
Vap.Perm:
Sorption: KKH->LA (Spruce).
HydrCond: Dummy values (liquid flow not active)
Suction : Dummy values
COC 130503
```

```
*Solidwood - Picea abies LEFT SHIFT
1         0.01      0.77      0.9
400.0     2500.0    7.0       0.10      0.17      0.21      0.0
DELTAL_X  0.0000        0.2017      0.4034      0.5042      0.6050
0.6555      0.7059      0.7563      0.8067      0.8571      0.9000
0.9496      0.9800 *
DELTAL_Y  1.145E-12     1.463E-12   1.754E-12   2.396E-12   2.965E-
12   3.810E-12   5.065E-12   6.928E-12   9.693E-12   1.380E-11
1.870E-11   2.698E-11   3.500E-11
DELTAH_X  0.2942 *
DELTAH_Y  1.5E-11
ABSORP_X  0.0       0.205     0.440     0.6525    0.8585    0.955
0.986 *
ABSORP_Y  0.0       0.053     0.0875    0.123     0.1805    0.2495
0.306
DESORP_X  0.0       0.202     0.452     0.6523    0.8015    0.899
0.9535 *
DESORP_Y  0.0       0.063     0.111     0.1507    0.1995    0.244
0.2775
0.350     0.309     1.760
HYDCND_X  0.309 *
HYDCND_Y  1.0E-50
SUCABS_X  -10.0     14.786 *
SUCABS_Y  0.309     0.2951
SUCDRY_X  -10.0     14.786 *
SUCDRY_Y  1.76      0.2938
 Solidwood LEFT SHIFT, 400 kg/m3, k=0.10 W/mK, d=1.145E-12 / 3.5E-
11 kg/msPa
Vap.Perm:
Sorption: KKH->LA (Spruce).
HydrCond: Dummy values (liquid flow not active)
Suction : Dummy values
COC 130503
```

Explanation to material setting abbreviations:

```
MATERIALER MED VELDEFINERET TYKKELSE OG KAPACITET

Mat.navn
'*' and matname max 254 karak.

1         standard  sol       langbølget
          tykkelse  absorpt.  emissivitet
          delx      Absorp    Emiss
Digit 1   [m]       [-]       [-]
```

```
{ Termiske parametre }

tør       termisk   fryse.pu. termisk   fugt afh. is afh.   temp.
afh.
densitet  kapacitet depress.  varmeled. varmeled. varmeled.
varmeledningsevne.
ro        cp        dtfreez   lambda10  lambdauw  lambdaui
tclambda
[kg/m3]   [J/(kg·K)][K]       [W/(m·K)] [W/(m·K)] [W/(m·K)]
[W/(m·K²)]

{ Damptransport- og sorptionsparametre }

DELTAL_X  RF-afgivelse i delta-RF kurve (i det hygroskopiske
område) [-].
          Liste af een til n numre afsluttet med karakteren *
DELTAL_Y  Damppermabillitets angivelse ("delta") i delta-RF kurve
[kg/(m·s·Pa)].
          Liste med samme antal numre som angivet ved DELTAL_X
(ingen afslutning)

DELTAH_X  u-angivelse i delta-u kurve (i det over-hygroskopiske
område) [kg/kg].
          Liste af een til n numre afsluttet med karakteren *
DELTAH_Y  Damppermabillitets angivelse ("delta") i delta-u kurve
[kg/(m·s·Pa)].
          Liste med samme antal numre som angivet ved DELTAH_X
(ingen afslutning)

ABSORP_X  RF-angivelse i sorptionskurve (u-RF) (ved absorption) [-
].
          Liste af een til n numre afsluttet med karakteren *
ABSORP_Y  Vandindholdsangivelse ("u") i absorptionskurve [kg/kg].
          Liste med samme antal numre som angivet ved ABSORP_X
(ingen afslutning)

DESORP_X  RH-angivlese i sorptionkurve (u-RF) (ved desorption) [-].
          Liste af een til n numre afsluttet med karakteren *
DESORP_Y  Vandindholdsangivelse ("u") i desorptionskurve [kg/kg].
          Liste med samme antal numre som angivet ved DESORP_X
(ingen afslutning)

{ Væsketransport- og suctionparametre }

Kritisk   Kapillar  Vacuum
vandmæt.  vandmæt.  vandmætningsgrad
ucr       ucap      uvac
[kg/kg]   [kg/kg]   [kg/kg]

HYDCND_X  u-angivlese i hydraulisk ledningsevne afhængighed af
vandindhold (Kliq-u) [kg/kg].
          Liste af een til n numre afsluttet med karakteren *
HYDCND_Y  Hyraulisk ledningsevne-afgivelse ("Kliq") i Kliq-u Kurve
[kg/(m·s·Pa)].
          Liste med samme antal numre som angivet ved HYDCND_X
(ingen afslutning)

SUCABS_X  ln(PSuc)-angivelse i suction-kurve for absorption ln[Pa].
          Liste af een til n numre afsluttet med karakteren *
SUCABS_Y  Vandindholdsangivelse i u-ln(PSuc) absorptionkurve
[kg/kg].
```

```
          Liste med samme antal numre som angivet ved SUCABS_X
(ingen afslutning)

SUCDRY_X  ln(PSuc)-angivelse i suction-kurve for udtørring ln[Pa].
          Liste af een til n numre afsluttet med karakteren *
SUCDRY_Y  Vandindholdsangivelse i u-ln(PSuc) desorptionkurve
[kg/kg].
          Liste med samme antal numre som angivet ved SUCDRY_X
(ingen afslutning)

{ Kommentar }

Kommentar linier. Mindst een linie (som er indrykket een karakter)
er nødvendigt.

-------------------------------------------------------------------
MATERIALER UDEN KAPACITET (ENKELTMODSTANDE)

Mat.navn
'*' og matname

0         termisk  fugt
          modstand modstand
          R         Z
digit 0   [m²K/W]   [GPam²s/kg]

{ kommentar }

Kommentar linier. Mindst een linie (som er indrykket een karakter)
er nødvendigt.

--------------------------------------------------------------------
```