Vikberg, T., Elustondo, D. (2016)
Basic density determination for Swedish softwoods and its influence on average moisture content of wood packages estimated by measuring their mass
Wood Material Science & Engineering, 11(4): 248-253
https://doi.org/10.1080/17480272.2015.1090481

Basic density determination for Swedish softwoods and its influence on average moisture content of wood packages estimated by measuring their mass*

TOMMY VIKBERG [1,2] & DIEGO ELUSTONDO [1]

[1] Luleå University of Technology, Forskargatan 1, SE-931 87 Skellefteå, Sweden, phone:+46 920 49 10 00, tommy.vikberg@ltu.se, [2] SP Technical Research Institute of Sweden, SP Wood Technology, Laboratorgränd 2, SE-931 77 Skellefteå, Sweden, phone: +46 105 16 50 00, tommy.vikberg@sp.se.

*Reformatted version of paper available at: http://dx.doi.org/10.1080/17480272.2015.1090481

Abstract

In this work, a setup with a device measuring the mass of wood packages is examined as an aid to estimate the average moisture content of wood packages. As the basic density needs to be presumed in the setup, an estimator of the basic density as function of log diameter is determined for Norway spruce (*Picea abies (L.) Karst*) and Scots pine (*Pinus sylvestris*). In total 1920 specimens were collected at two different sawmills and analysed for this purpose. Specimens collected at the butt-end of pine had the greatest variation in basic density and it is recommended that they should be omitted when sawmills create their own functions for basic density estimation. Furthermore, the variation in basic density was shown to have the greatest impact on the estimated moisture content. A maximum error estimator of the moisture content became 14 % at a moisture content of 70 % and 9 % at a moisture content of 10 %. It was therefore concluded that the described method should not be used to estimate the moisture content of packages after drying but can serve as a valuable indicator of average green moisture content of a drying batch.

Keywords: Wood drying, Sawmill, Scots pine, Norway spruce, Load cells.

Introduction

In the Nordic Countries, the two species of the greatest commercial interest are Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies (L.) Karst*). When they grow mature, heartwood is formed in the centre of the trunk which does not actively take part in the water transport in the stem (Taylor et al. 2002). The heartwood therefore dries out and the moisture content (MC) of heartwood in a green tree is in the range of 30 to 50% whereas the MC in the sapwood is in the range of 100 to 200% for pine and spruce species (Tamminen 1962, 1964).

Since wood is a hygroscopic material, the MC of the sawn timber will be in equilibrium with its surrounding in the final use. For timber that shall be used in a dry indoor climate this implies around 8% MC and for timber used in constructions around 18% MC (Skaar 1988). It is also well known that wood shrinks when it dries to MC below the fibre saturation point and that the shrinkage is anisotropic. The result of further processing such as planning and gluing is also correlated to the MC of the timber. Consequently, the MC level of the sawn timber is one of the parameters that sawmills want to ensure their customers.

Today, all sawmills of reasonable size dry their timber in air circulating kilns (Staland et al. 2002). If it was possible to provide the kiln with the same raw material and keep the drying process exactly at a predefined schedule the outcome would always be the same. This is, however not the case, caused both by variations in the ingoing wood parameters as well as process disturbances. The single largest factor affecting the average MC of the sawn timber is the heartwood-sapwood ratio due to their different green MCs. It is also well known that the drying rate of sapwood is much higher than of heartwood and in a drying process they will eventually reach the same MC. Salin (2002a) shows that this occurs at roughly 12% MC for Scots pine with average basic density of 430 kg/m^3 and a standard deviation in basic density of 30 kg/m^3. Knowing the exact MC distribution of a drying batch or the average MC with high accuracy is therefore not important for the kiln operator. In the late spring and early summer, bad carrying capacity of many forest roads together with a dry outdoor climate can however result in a major pre-drying of the sapwood in whole drying batches.

Persson and Andersson (2014) measured average MC of freshly sawn timber batches of the same product ranging between 64% and 82% with the lowest values during the summer. They also showed by simulations that the corresponding difference in drying time to reach a final MC of 18% would be approximately 11 hours. Due to the relatively low drying rate in the diffusive regime, a few hours more or less in drying time will not affect the average final MC to a great extent. Drying to a lower MC than the target, nevertheless always represents a waste of energy and drying capacity and increase the distortion of the wood. In later production steps, when sawn timber from different drying batches are mixed, the total MC variation will also increase even if the single drying batches have only slightly different average MCs. As sawmills usually have a large number of drying kilns, even small improvements in each drying process also sum up to a major improvement in terms of drying capacity.

The extensive pre-drying of the sapwood that sometimes occurs causes problems for the kiln operators to hit the designated final MC. To stop the kiln and make an extra check with a resistive meter to determine if the target MC is reached is a possible solution but demands extra labor hours and results in decreased drying capacity. More information of the drying batch which can help the kiln operator to make the right decisions is therefore desirable. Numerous ways to provide the kiln operators with data to help them control the drying process and reach the designated final MC has been developed and tested out in the industry. Some methods are based on estimating the wood MC from measurements such as the following (Fløtaker and Trondstad 2000, Vikberg 2012):

- load cells weighting whole stacks both prior, during, and after drying
- measuring the height of the packages during drying, which is correlated to the MC through the shrinkage
- resistive measurement of the MC on a few boards per batch during drying
- capacitive measurements of the batch during and after drying

Other methods are based on computer simulation software – offline to create fixed schedules or online to adjust adjacent climate (Hukka 1996, Salin 2002b, Salin and Wamming 2008). Measurement systems that have to be implemented in each one of the kilns imply a large investment and increased demand of maintenance. One single computer can, however, be used to run all the drying simulations at a sawmill. To get a reliable result from the simulation software it is important to provide it with the correct input data in terms of species, basic density, MC, volume and kiln characteristics. Out of this, the basic density and MC are the two most difficult parameters to estimate.

Earlier work suggested extracting this information out of X-ray data from the log sorting station (Skog et al. 2010). However, if the sorted logs stay long in the log yard before they are sawn, then they will become pre-dried and the MC measured in the log sorting station will be outdated. This problem is possible to overcome by instead installing the measuring device in the green sorting. Another problem is that X-ray devices working with only one energy level lack the possibility to distinguish between wood and water substance. This could be potentially solved by using dual-energy X-ray devices (Tanaka and Kawai 2013), but the reported measurement duration with existing dual-energy X-ray systems is too long for the method to be implemented online in a sawmill (Hultnäs and Fernandez-Cano 2012, Tanaka and Kawai 2013).

If the volume of the timber and its basic density is known, then the MC could instead be measured by utilizing a balance or a single-energy X-ray. Today the volume is commonly well defined by a supplementary measuring device, thus the problem reduces to measure or estimate the woods basic density.

The aim of this study is therefore to generate functions for the wood basic density at two sawmills in Sweden. An extensive discussion is also given regarding sources of errors and their magnitude in a setup for utilizing a balance or a single-energy X-ray to estimate the average MC of a wood package.

Material and Methods

Material preparation

In this study center yield from Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies (L.) Karst*) logs were considered. Specimens were collected at two different sawmills, one located in Northern Sweden (hereafter denoted sawmill 1) utilizing both pine and spruce and one in Central Sweden (hereafter denoted sawmill 2), utilizing only spruce. Specimens were collected at 64 occasions over a time span of two years. At each occasion, 30 oven-dry specimens were collected according to the standard SS-EN 13183-1 from three different packages. From each package, five specimens were taken approximately 40 cm from the boards' butt-end and five specimens were taken approximately 40 cm from the boards' top-end. In addition, the dimension of each oven-dry specimen was measured with a caliper for making determination of specimens' basic density ($\rho_{0,green}$) possible. To ensure high production and high volumetric yield in the sawing process, the logs are presorted in different log-classes according to the logs top diameter. The sawmill then run one log-class at the time, which implies that all specimens collected at a certain occasion originated from the same log-class. The log-class and its corresponding log diameter interval were therefore also recorded.

Basic density analysis

A fundamental assumption throughout this work was that the basic density for a certain log-diameter and species does not vary significantly over the year for trees originated from the same growth area, i.e. the timber supply area of a certain sawmill. Under this assumption, linear equations of the basic density as function of log diameter were determined for the two sawmills. The basic density of the oven dry specimens was utilized in the analysis in which the following steps were taken:

- Data was examined for explainable outliers caused by error in the measurements.

- A Lilliefors test was performed with the null hypothesis "the sample originated from a normally distributed population". In the analysis, specimens from each log diameter were considered as sampled from their own distribution. Butt- and top-end specimens were also treated separately for further examination of differences in mean basic density. As rejection criteria, α=0.05 was used. As tests for normality are quite strict, histograms were used as a complement to judge if normality could be assumed.

- A two tailed t-test was performed to compare the mean value of the butt- and top-end samples of each log-class. The variances were assumed to be unknown and not necessary equal. As a rejection criteria, α=0.05 was used.

- Linear regression was performed and the root mean square error (RMSE) of the model was calculated.

- An analysis of the covariance of the basic density of butt- and top-end samples for pine was performed with the null hypothesis that the estimated relation with the log diameter was the same. α=0.05 was used as rejection criteria.

Error estimation

The magnitude of errors in the estimated moisture content, (u) was achieved by maximum error estimation. The analysis start with the expression of u as a function of the measured total volume (V), the mass (m) of the package, and the estimated average basic density (ρ):

$$u(m,\rho,V) = \frac{m-\rho V}{\rho V} = \frac{m}{\rho V} - 1 \tag{1}$$

Equation 1 was then differentiated:

$$\Delta u \approx \left(\frac{\partial u}{\partial m}\right)\Delta m + \left(\frac{\partial u}{\partial \rho}\right)\Delta\rho + \left(\frac{\partial u}{\partial V}\right)\Delta V = \frac{1}{\rho V}\Delta m - \frac{m}{\rho^2 V}\Delta\rho - \frac{m}{\rho V^2}\Delta V \tag{2}$$

By using the fact that the mass, volume and basic density all are positive numbers and some algebra, Equation 2 was then rewritten to form the maximum error estimator:

$$|\Delta u|_{max} \lesssim (u+1)\left(\frac{|\Delta m|_{max}}{m} + \frac{|\Delta\rho|_{max}}{\rho} + \frac{|\Delta V|_{max}}{V}\right) \tag{3}$$

Equation 3 shows that the error in u is proportional to the relative errors in the measured/predicted mass, basic density and volume. In addition, the equation shows that the error can be separated in two components: One component that increases proportionally to u and a component that is independent of u.

The magnitude of the error depends on how the quantities are measured but to get an idea of the total maximum error, a maximum relative error of 1 % of the measured mass was assumed. This is a reasonable assumption if the mass is measured with load cells. The accuracy of each cross sectional dimension was assumed to be within 0.2 mm and the accuracy of the length to be within 3 mm. The maximum relative error in the volume for a package with small dimensional boards (i.e. 28x100 mm^2) with an average length of 4 m then becomes 1 %. The magnitude of the relative error in basic density was achieved by first calculating the pooled estimator of the variance (Montgomery et al. 2004) of the basic density from all log-classes of top-end pine, butt-end pine, spruce at sawmill 1, and spruce at sawmill 2 respectively. Packages were then simulated where each boards basic density was taken from a normal distribution with this variance. Each package consisted of only 100 different boards. The reason for this small number is that several boards are usually sawn out of each log and the basic density of boards origin from the same log is similar. As an estimator of the maximum relative error in basic density, the maximum deviation between a single package and the total mean basic density was utilized. In total 500000 packages was simulated.

Results and Discussion

Basic density

Out of the total number of specimens, no explainable outliers were found despite the spread was large. The Lilliefors test resulted in a rejection of the null hypothesis for 7 samples out of 60 (i.e. 30 different log-classes with the butt- and top-end samples analyzed separately). The samples for which the null hypothesis was rejected were examined with aid of histograms and it was found that the assumption that each of the specimens were collected from a normal distribution seemed reasonable.

Considering differences in basic density between butt- and top-end samples, the null hypothesis that there was no difference in the mean value could be rejected for only 4 out of 20 log-classes of spruce and 8 out of 10 log-classes of pine. Due to the result of the t-test, it was reasonable to make no distinction between butt- and top-end samples for spruce but to treat butt- and top-end samples from pine separately. A Lilliefors test was performed on the spruce samples after merging the butt- and top-end samples together, and the null hypothesis was rejected for 5 out of 20 samples. The samples for which the null hypothesis was rejected were examined with aid of histograms and it was reasonable to assume that the butt- and top-end samples were collected from the same distribution.

Box plots, together with linear regressions and the RMSE are shown in Figure 1-4. The large RMSE indicates the importance of collecting a large number of specimens to determine an accurate function for estimating the basic density.

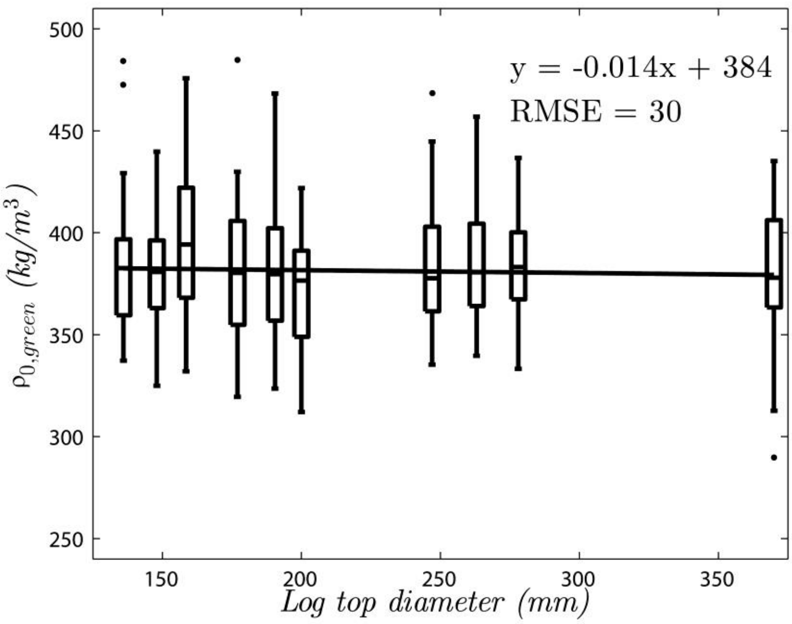

Figure 1. Box plot and linear regression for Pine basic density samples collected at the top-end of the boards. The linear equation and the root mean square error are shown in the figure. The boundaries of the box are the 25^{th} and the 75^{th} percentile and the line in the box is the median value. The maximum length of the whisker is 1.5 times the interquartile range and observations outside this range are represented by a dot. This is also what is shown in Figure 2 to Figure 4.

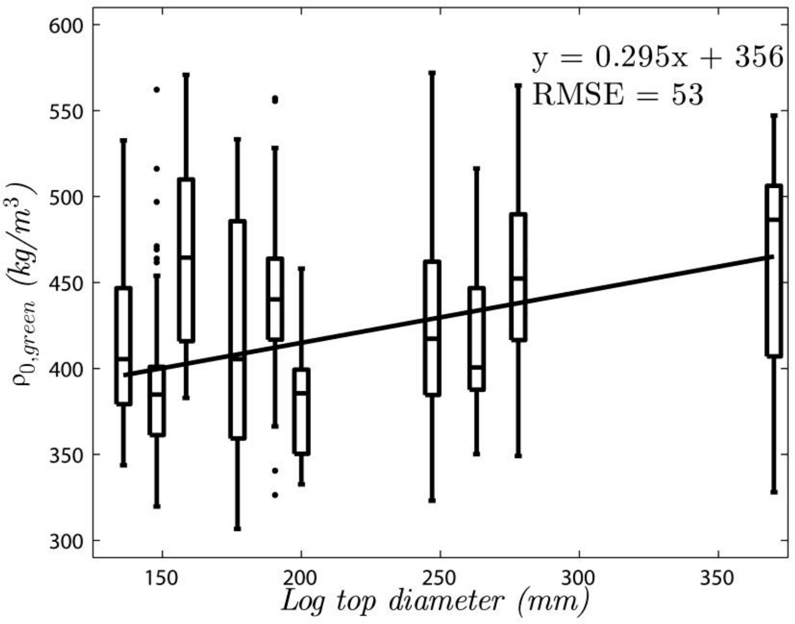

Figure 2. Box plot and linear regression for Pine basic density samples collected at the butt-end of the boards.

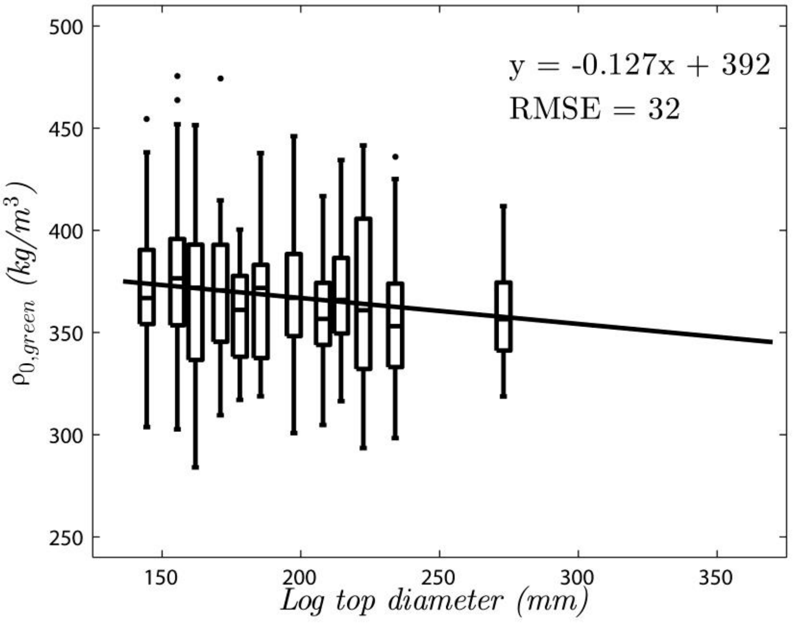

Figure 3. Box plot and linear regression for Spruce basic density samples collected at sawmill 1.

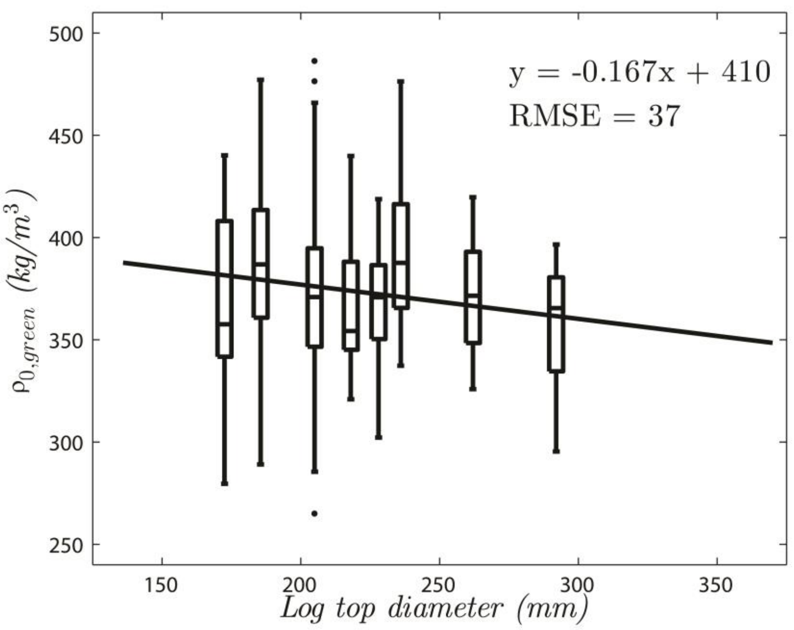

Figure 4. Box plot and linear regression for Spruce basic density samples collected at sawmill 2.

By comparing Figure 1 and 2, it can also be seen that butt-and top-end specimens from pine behave differently. A possible cause is that some of the butt-end specimens originated from the trees' butt-logs (i.e. if they were cut from the first log of the tree). Top-end specimens are on the other hand always cut at some distance from the butt-end of the living tree (i.e. at least one log-length). This affects basic density as it is well known that pine has their largest amount of extractives in the butt-end of the tree (Tamminen 1962). A further complication was caused by the fact that sawmill 1 tries to sort log-classes excluding the trees' butt-logs for some diameter intervals. In Figure 2, log-classes where sawmill 1 excluded trees' butt-logs are the 2^{nd} and 6^{th} log-classes counting from the left. Depending on how successful this sorting was, the proportion of butt-logs differed in these log-classes, as well as in the log-classes in which butt-logs otherwise is sorted (i.e. a mixed log-class in which the butt-log is sorted if it is classified as not being a butt-log). As the butt-log always has larger diameter than the subsequent logs from the same tree, the largest diameter log-classes will also contain a higher proportion of butt-logs. One solution could be simply excluding the butt-end specimens and using only top-end specimens for measurements. This, however, would be wrong from a drying point of view. We therefore recommend to develop functions for estimating basic density for pine from specimens cut at the top-end of the boards, but then to add a "butt-log fraction" adjusting for the amount of higher density wood in the package. The null hypothesis that there were no differences in the linear regressions for pine butt- and top-end samples was also rejected in the analysis of covariance.

Estimation of moisture content and errors

The square root of the pooled estimator of the basic density variance calculated with the values presented in Table I to IV became 30, 50, 32, 37 kg/m^3 for top-end pine, butt-end pine, spruce at sawmill 1, and spruce at sawmill 2 respectively. The corresponding maximum relative error in basic density became 4, 6, 4 and 5 %. The magnitude of the maximum relative error in basic density shows that there is no reason to invest in systems determining the mass and volume with extremely high accuracy.

If the green MC is approximately 70 %, the total maximum error according to Equation 3 thereby become 11, 14, 11, and 12 % MC for respectively top-end pine, butt-end pine, spruce at sawmill 1, and spruce at sawmill 2. The corresponding maximum errors after drying with an average MC of 10 % become 7, 9, 7 and 8 % MC (n.b. this reported errors are in percentage-units and not a percentage of the mean MC).

Table I. Pine top-end specimens.

Log top diameter (mm)	136	148	158.5	177	190.5	200	247	263	278	370
Number of specimens	30	120	15	30	30	30	60	15	30	15
Av. basic density (kg/m^3)	384	382	397	380	383	371	382	386	386	374
Std. basic density (kg/m^3)	35	26	42	38	32	27	27	31	28	39

Table II. Pine butt-end specimens.

Log top diameter (mm)	136	148	158.5	177	190.5	200	247	263	278	370
Number of specimens	30	120	15	30	30	30	60	15	30	15
Av. basic density (kg/m^3)	413	387	469	416	439	383	425	420	452	464
Std. basic density (kg/m^3)	46	38	56	68	54	34	60	51	51	64

Table III. Spruce specimens from sawmill 1.

Log top diameter (mm)	144.5	155.5	162	171	178	185.5	197.5	208	214.5	222.5	234	273
Number of specimens	60	90	60	30	30	30	120	30	90	30	60	30
Av. basic density (kg/m^3)	372	378	369	370	358	382	369	361	368	367	358	360
Std. basic density (kg/m^3)	31	34	37	36	23	30	29	25	28	43	36	27

Table IV. Spruce specimens from sawmill 2.

Log top diameter (mm)	172.5	185.5	205	218	228	236	262	292
Number of specimens	30	120	210	30	30	30	30	30
Av. basic density (kg/m^3)	370	382	374	365	365	390	369	358
Std. basic density (kg/m^3)	40	37	40	30	30	34	26	28

Conclusions

The estimation of the basic density is the largest source of error if decent equipment is used to measure the mass and volume. The large magnitude of the derived maximum error shows that the described method should not be utilized to estimate the MC of dried packages or even individual green packages. The method could however still be used to estimate the average green MC of a drying batch consisting of several wooden packages. Especially when a major pre-drying of the sapwood is present, the method can be a valuable indicator to the kiln operator when actions need to be taken to hit the designated final MC of the drying batch. Finally, because of the large variation in the basic density of butt-end specimens from pine we recommend that they should be omitted when deriving basic density estimators.

References

Fløtaker, S., and Tronstad, S. (2000) *Description and initial test of 8 principles for in-kiln measuring and end-point control of wood moisture content*, IMCOPCO (task 2.1). Norwegian Institute of Wood Technology, Oslo.

Hukka, A. (1996) *A Simulation Program for Optimisation of Medium Temperature Drying on an Industrial Scale*. In proceedings of the 5th International IUFRO Wood Drying Conference, Quebec City, Canada, August 13-17.

Hultnäs, M., and Fernandez-Cano, V. (2012) Determination of the moisture content in wood chips of Scots pine and Norway spruce using Mantex Desktop Scanner based on dual energy X-ray absorptiometry. *Journal of Wood Science*, 58(4): 309–314.

Montgomery, D.C., Runger, G.C., and Hubele, N.F. (2004) *Engineering statistics*, (New York: John Wiley & Sons).

Persson, F., and Andersson, J.E. (2014) *Automatisk övervakning och uppföljning av torkprocessen – paketvägning*, (In Swedish). Wood Centre North, Luleå University of Technology, Skellefteå.

Salin, J.G. (2002a) *The timber final moisture content variation as a function of the natural variation in wood properties and of the position in the kiln load. An evaluation using simulation models.* In proceedings of the 4th COST E15 Workshop, Santiago de Compostela, Spain, May 30-31.

Salin, J.G. (2002b) *Simulation models as an industrial tool for optimizing the drying of timber*. In proceedings of the 4th COST E15 Workshop, Santiago de Compostela, Spain, May 30-31.

Salin, J.G., and Wamming, T. (2008) Drying of timber in progressive kilns: Simulation, quality, energy consumption and drying cost considerations. *Wood Material Science and Engineering*, 3(1-2): 12-20.

Skaar, C. (1988) *Wood -Water Relations*. (Berlin Heidelberg: Springer Verlag).

Skog, J., Vikberg, T., and Oja, J. (2010) Sapwood moisture-content measurement in Pinus Sylvestris sawlogs combining X-ray and three-dimensional scanning. *Wood Material Science and Engineering* 5(2): 91-96.

Staland, J., Navrén, M., and Nylinder, M. (2002) *Såg 2000, Resultat från sågverksinventeringen 2000* (Saw 2000, Results from sawmill inventory 2000), (In Swedish). The Swedish University of Agricultural Sciences, Uppsala.

Tamminen, Z. (1962) *Fuktighet, volymvikt m.m. hos ved och bark I. Tall. (Density and Other Properties of Wood and Bark I. Scots Pine)*, (In Swedish). Research Note 41, Royal School of Forestry, Department of Forest Products, Stockholm.

Tamminen, Z. (1964) *Fuktighet, volymvikt m.m. hos ved och bark II. Gran. (Density and Other Properties of Wood and Bark II. Norway Spruce)*, (In Swedish). Research Note 47, Royal School of Forestry, Department of Forest Products, Stockholm.

Tanaka, T., and Kawai, Y. (2013) A new method for nondestructive evaluation of solid wood moisture content based on dual-energy X-ray absorptiometry. *Wood Science and Technology*, 47(6): 1213-1229.

Taylor, A.M., Gartner, B.L., and Morrell, J.J. (2002) Heartwood formation and natural durability –a Review. *Wood and Fiber Science*, 34(4): 587-611.

Vikberg, T. (2012) *Moisture content measurement in the wood industry*. Licentiate Thesis, Luleå University of Technology, Sweden.