SMOKEWOOD™

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- Energy consumption

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Based on the materials and research in Europe (VTT, Finland) and in the US (Westwood)

Features of Smokewood

Parameter	Effect	Comments
Equilibrium moisture	Reduced 50% compared untreated wood. The dif-ference is higher, the relative humidity is higher.	This difference remained after years of exposure. After thermo treatment the wood is dry - moisture content is 4-6%.
Dimensional stability	The swelling and shrinkage (both tangential and ra-dial) reduces 3-5 times for softwoods and up to 15 times for hardwoods. This parameter is strongly de-pends on the relative humidity (at 100% reduces 2 times for softwoods and 3-5 times for hardwoods)	This because of the decrease in absorptive qualities, lower equi-librium moisture content and also due to lignin depolymerization the length of chains of cellulose decreases and this leads to the deformations decrease.
Color	Attractive golden brown appearance and even color at all depth.	The color is affected by the treatment temperature and time. It is possible to receive several gradations of color based on the process.
Appearance	Attractive golden brown appearance and even color at all depth. Color becomes more sated and homogeneous on all section; the structure of wood effectively comes to light.	The color is affected by the treatment temperature and time. It is possible to receive several gradations of color based on the process. The effect of valuable breeds of wood is reached.
Density	Lower density at 5-10%.	Due to the emissions during the thermo-treatment process and lower equilibrium moister content. This feature might improve the cost-efficiency of shipping of the treated material.
Cell structure	Changes as if after ageing for 120-250 years.	The color is affected by the treatment temperature and time. It is possible to receive several gradations of color based on the process. The effect of valuable breeds of wood is reached while the absorption of moisture is decreased.
Resin	Is almost fully removed.	
Brinell hardness	Increases as the treatment temperature increases. However, the relative change is very small, as the density decreases.	Certain kinds of timber change their place on the hardness scale, as some of them become harder, while others softer as a result of the treatment temperature and specie.
Permeability	The water uptake reduced up to 5 times depending on treatment temperature.	The surface of the thermo-treated wood is not porous but solid, also the chemical composition of the wood changes. Reduced water absorption has to be taken into account when working with water solvent glue or paint.
Thermal conductivity	Decreased by 10-30%.	Thanks to the lower water content and structural changes.
Fire resistance	The same as non-treated wood. Thermo--treated wood is in fire class D.	The time of ignition a little decreased, but better than the normally dried softwoods in terms of heat and smoke release.
Resistance to insect attack and termites	Significantly increased resistance to the hardwood and softwood insects, but only a little increased resistance to the termites (it is expected that termites will choose normal wood over thermo-treated).	Tests have been carried out in Europe to evaluate the resistance to attack from the three most common wood boring insects found in Europe. House Longhorn beetles (Hylotrupes bajulus) are found in the sapwood of softwood, the common furniture beetle (Anobium punctatum) preferentially attacks hardwoods and the Powderpost beetle (Lyctus brunneus) is found in some hardwood species. The results of the tests found that thermo treated wood was resistant to all three of the above insect species. Southern European Subterranean termites (Reticulitermes spp) found in Europe only attack buildings from the earth below, avoid-ing direct sunlight where possible. Termites will attack both wood and concrete based materials in their quest for a strong food base. Various measures have been developed to control the prob-lem including polythene membranes being installed in the founda-tions and various bituminous paint products are available to seal possible routes up the building.
Rot resistance	Improved.	However it is not suitable for conditions where it would be satu-rated with water or in prolonged contact with damp ground.

Parameter	Effect	Comments
Biological durability	European tests on biological durability of thermo treated wood in EN 113, ENV 807 standards showed significantly improved level of resistance against fungi attack (15-25 times) depending on treatment temperature.	Thermo-treated wood does not require any chemical protection. Due to high heat of processing in wood decay hemi-cellulose and poly-sugars, that on a background of low equilibrium humidity eliminates conditions for occurrence and duplication of a fungus and microorganisms. Biodamaging agents (insects and those lar-vae, bacteria, fungi and their disputes) are destroyed. According to tests the wood, treated at 410F should obtain dura-bility class 2; upper 430F with 3 hours of treatment is class 1 (30 years service life outdoor). The best results can be achieved when the material is used in above ground applications with good ventilation and no water-trapping.
Weather resistance	As every natural material exposed to weather ef-fects (ultraviolet radiation and rain) it will start to grey without coating in approximately one summer. When left without surface protection small surface shakes can also appear. Level of surface shakes for treatment below 445F (softwood) is the same than untreated material, for the higher temperatures and hardwoods the result is insignificantly better.	As the thermo-treated wood has even brown color in depth, the original color can be easily restored by simply sanding the sur-face. Or recommended to apply a pigment based surface protec-tion to prevent color changes and surface shakes. Strongly recommended apply of high-build stains and oils protected (the best are priming oil and solvent-based alkyd or water-based acrylic topcoat), otherwise the low-build coatings wore away and annual rings started to loosen just as in the panels without coat-ing. The panels coated with the low-build stains showed a strong tendency to crack. Due to bacteria in the air or dirt carried in the rain, fungi can grow on the untreated surface. However, this is on the surface only and can be removed by wiping or scraping.
Ground contact	Not recommended to be used in deep ground ap-plications where structural performance is required.	It is assumed that the indicated loss of strength is due to moisture and to any micro-organism. However practical experience has found that usage of highest temperature treated material in ground contact where structural performance is not critical and periodic drying of the surfaces is allowed does not cause any sig-nificant deterioration to the material. This is especially apparent when the ground has good drainage and is made up of sand or shingle.
Emissions	Total volatile organic compounds are significantly lower (250-800 mg/m2h) than with normal kiln dried material (1500 mg/m2h).	The most of thermo-treated wood emission is acetic acid (110 mg/m2h). The smoke-like smell that comes out of thermo-treated wood (most likely comes from furfural) disappears almost totally with time or after coating.
Environmental purity	Absolutely.	The thermo-treatment is made without insertion of any chemicals. With guarantees at least the same class of durability as the chem-ically protected wood, thermo-treated wood holds no danger for the environment.
Utilization	Needs no additional conservation	Can be easily utilized at the end of its life cycle unlike the chem-ically treated lumber.
General strength	Reduced proportionally the density reduction.	Generally the strength of wood has strong correlation with den-sity. Thermo treated wood has slightly lower density and corre-lated lower strength values, but weight-strength-value can be practically unchanged.
Bending strength	Lower (1-30%) especially for lumber with knots and highly depends on treatment temperature.	It is recommended that deep thermo treated wood is NOT used for load bearing structural usage. On the other hand, it was found that the light treatment renders positive influence on elasticity of molecules of wood.
Dynamic bending strength	Lower (1-25%) especially for lumber with knots and highly depends on treatment temperature.	
Compression strength	The thermo-treatment process has no negative ef-fect on the compression strength values. More-over, in some cases results better, than for dried up wood.	This property depends mainly on density of wood.
Shear strength	Radial values reduced 1-25 percent and tangential values 1-40 percent.	Highly depends on treatment temperature.
Splitting strength	Reduces 20 -40 percent depending on treatment temperature.	Hardwoods show better results than softwoods.
Screw holding strength	The screw holding strength has strong correlation with density. Bigger effect on screw holding strength comes from the general variance in wood density than thermo-treatment process.	It was found that the results were better when narrower pre-drill holes were used for material with lower density.

Working with Smokewood

The performance of Thermo-treated wood differs from normal wood. As the wood has becomes brittle, sharp blades have to be used to prevent the wood from ripping. The wood dust coming from the process is very finely divided and dry. Thermo-treated wood is suitable for jobs involving gluing with all glue and paint types. When water-based glue or paint is used, the longer drying time due to diminished absorption of water must be taken into consideration (mostly for softwoods). Normal painting and gluing processes present no problems with hardwoods. The darkened color created in the process is not durable in UV-light, unless the surface is treated with UV-resistant coating. This also enhances the product's performance against checking. Thermo-treated wood is more susceptible to mechanical damages compared to untreated wood. Thermo-treated wood can be sawn and worked in the same way as untreated lumber. It is easy to use all sorts of hand tools for cutting, drilling and planning. An excellent surface can be created without any difficulty, and drilling through knots is also easy.

Storage.
Thermo-treated wood can be stored for unlimited time in a dry place, including unheated warehouse. The packages should be stored off the ground and flat with sufficient supports between packs to avoid distortion.

Raw material.
Preliminary K/D must be soft and slow to avoid honeycombs and reduce tension. It is very important to select raw material without heart shakes, soft rot and dead knots, which are likely to drop out during thermo treatment. Sideboard material is less suitable for thermo treatment process. More vertical grained material leads to better end results.

Mechanical treatment.
All working techniques (sawing, planning, milling, drilling, turning and sanding) can be carried out with the regular tools and according to established working practices. To achieve the best results the use of well-sharpened hard metal blades is recommended. The following measures can lead to further improvements in quality:

- ✓ Increasing the cutting angle and also if possible, the clearance angle
- ✓ Increasing cutting speed
- ✓ Using tools with the highest possible number of blades
- ✓ Using parallel feed whenever possible

Due to the intensity of thermo treated wood is more brittle than untreated wood and therefore sharp edges (via chamfering or rounding) should be avoided.

Fixing.
Adhesive Fixing
Since the wood is entirely dried out, cases of insufficient adhesive strength may arise. It is important to carefully check if the required adhesive stability can be achieved when using water-based glues. Water -based glues, such as PVA requires longer compression and drying time when applied to softwoods. No significant difference for thermo-treated hardwoods when compared with non-treated wood. Due to brittleness of thermo-treated wood high compression pressures should be avoided. The glue used should also contain a high proportion of solid material.
Chemically hardening glues (such as polyurethane, glue based on polyvinyl acetate + hardener, resorcinol phenol and melamine resin) can be used with thermo-treated wood in the same way as with non-treated wood.
As levels of expansion and contraction in thermo-treated wood are 50% lower than ordinary wood, it cannot simply be attached to un-treated wood. In these cases, careful preparation of both the thermo-treated and untreated wood is necessary. If raw plugs are to be used, then these should also be thermo-treated. Alternatively, plastic raw plugs could be used.
Up to now, no guaranteed results have been obtained on the performance of thermo-treated wood when adhesives are applied for external use. It is recommended not to use glue for external use.
When gluing thermo-treated wood, the glue manufacturer's specific Instructions must always be referred to.
Screwing
Thermo-treatment reduces splitting strength of wood. The use of self-tapping or countersinking screws or pre-drilling of holes must be made to avoid cracking of the material. It is recommended to use less threaded screws compared with untreated wood. Stainless steel screws with coun-tersunk heads are most suitable in outdoor applications.

Nailing

When fixing thermo-treated wood it is extremely important to use stainless steel – rust free or fully galvanized nails. Using normal wire nails or staples will lead to rust stains and overall deterioration in the fixing. Small oval head nails reduce the risk of splitting. Nails should be sunk to a depth of about 1/16”. Best results are gained when using a compressed air nail gun with adjustable nailing depth on the gun. Attention must be paid to the correct pressure and the nailer’s drive length.

Using a normal hammer increases risk of splitting due to accidental hammer contact with the wood.

Due to the brittleness fixing with nails, nail plates (gang nails) and staples is only of limited use of the material.

Recommended amount of fixings and positioning.

The nail position from the bottom of the board must be a minimum 2 times and maximum 3 times the thickness of the board. When fixing also at the upper part of the board the nail should be positioned minimum 2 times and maximum 3 times the thickness of the board at its thickest point down from the top of the board. The importance of this is that there should be sufficient overlap between adjacent boards, but it is important not to have the fixing too close to the point where the overlap occurs. It is absolutely crucial that the fixings are not positioned through the two adjoining boards. A sufficient clearance gap between each board should be maintained to allow for tangential movement and also free space for drying when the material is wet. The recommended clearance gap is between 2–3% of the total width of the board.

Planing.

Planing of thermo-treated wood can be made by using standard planning machines, which work well and also the surface quality is high. Good results are achieved with hard metal blades in cutters - the best results are achieved with carbide-tipped cutters.

Some care should be taken in the set up of the infeed rollers to reduce the risk of material cracking. Due to the cupping of pieces that may occur as a result of thermo treatment it is recommended that when planning pieces not previously re-cut to change the infeed roller to one that has two narrow wheels so the contact with the piece is at the outer edges of the convex face. Alternatively, a single narrow wheel can be used so that the piece is turned with the convex face down.

Both methods enable a flat surface to be formed as the piece proceeds through the planer, thus reducing the risk of surface cracking and enabling higher infeed roller pressure. In order to avoid cracking of the boards, it is advisable to make a flat base surface with a planer or band saw first before profiling.

Due to the lack of resin thermo treated pieces cause less friction during infeed and enable a smoother planing process. On the other hand, since the strength of the material is lower, the infeed rollers must be adjusted to lower pressures to avoid cracking of the boards. In some planing lines, the infeed speed must also be decreased (with correspondingly decreasing of rotation speed of the cutters). The exact thermo- treated wood planing parameters are set separately for each planing machine.

To achieve the best possible planing results and minimize loosening of the wood’s annual rings, it is recommended to use material that has been cut as parallel to the grain as possible. In addition, considering the best face of the board when planing improves the result. There is a close connection between the infeed roller type and pressure, the grain direction, cupping, cutter sharpness, and throughput speed. When these variables are carefully harmonized, the best results are achieved.

To avoid the risk of year ring loosening in end use it is important to plane the weather exposed surface to the outer side of the board and the heart side/pith to the backside or under side.

The raw material quality and number, size and type of knots has an effect on dulling of the cutters. Results have found that planing the boards so that the bottom end of the tree is put to the planer first brings better results. Too high pressure from the rollers and incorrect angles on the cutters can cause delaminating and year ring loosening.

Efficient dust extractions systems will be needed.

It has been found that with higher moisture contents the planing results improve. The standard moisture content of thermo-treated wood ranges from 3-5%, this moisture content fit will the equilibrium moisture content in relative humidity of 65%. If the moisture content is made too high then it can lead to shrinkage in end use especially if the product is to be used internally where the relative humidity is low.

It is important also to have a minimal gradient between surface and middle of the wood piece, too larger gradient can lead to distortion immediately after planing or deep cutting. Too larger gradient can also lead to the risk of surface fissures occurring.

Sawing.
Sawing of thermo treated wood does not differ from sawing of untreated wood. Sharp tools are recommended to achieve the best results. As the resinous substances have been removed during the thermo treatment process, the machines work well and are cleaner after processing.
Since gap-toothed saw blades can cause chipping in the edges of thermo treated pieces, fine-toothed blades are recommended. Blades with carbide or similar tips extend the saw blade's maintenance and sharpening intervals.

Milling.
In order to achieve a good surface quality – especially in milling – the cutters must be sharp; otherwise tearing will occur. A higher level of tearing was observed when the wood was milled across the grain. The greatest problems with tearing occurred at the start of the milling and at the end, when the cutter comes out of the wood. The cutting speed also affects the result. Milling thermo treated wood can be regarded as similar to working with hard, brittle hardwoods. It was found that the working order has an influence on the working properties of wood. The best results were achieved when there was enough solid wood material behind the cutter. Therefore, processing must be preplanned carefully. The cutters wear more slowly than with normal wood.

Sanding.
General working is equivalent to working with untreated wood; no problems have been reported. In many cases there is no need for sanding, as thermo treated was has a good surface quality after planing or milling. The dust generated has a small particle size, which is to be taken into account in planning dust extraction.

Surface treatment.
Reduced equilibrium moisture content of thermo treated wood improves its stability, which in turn reduces the cracking and flaking of the surface coating in changing weather conditions.
To prevent color changes and surface shakes it is recommended that surface treatment against ultra violet radiation is used. Normal painting processes present no problems, but when electrostatic painting is used, thermo-treated wood requires extra moisturizing. Coatings specifically designed for timber (such as water-borne, solvent-borne (sometimes referred to as oil based) or high solids solvent-borne in nature) can be used.
To prevent color changes, the treatment substance should contain pigment. This usually results in a slightly darker appearance. Different surface treatments have different maintenance intervals.
Because of the wood's natural state, some boards may check, or crack, more than others. This checking has no effect on the long-term durability of the product, nor does it affect Thermo-treated Products resistance to rot and decay. To enhance the product's performance against checking we recommend to apply the UV-protection sealant. We recommend a semi-transparent or clear treatment, which will allow the beautiful wood grain of Thermo-treated wood Products to show. One of the options is to use Penofin clear.
The end protection is very important to decrease water absorption through the end-grains.

Health and safety.
There is no major difference in health and safety considerations for thermo treated wood as compared to untreated lumber. The only detectable differences: the smell of the material and the dust generate in the processing of thermo treated wood.
Thermo-treated wood has a smoke-like smell, which likely comes from chemical compounds called furfurals. Although the smell is easily detectable and seems stronger than that of untreated wood, the tests show opposite results.
In processing of thermo-treated wood, special attention has to be paid to the operation of an appropriate dust extraction system. The standard dust extraction systems in industrial environments meet this requirement without requiring special adjustments.
Persons who are exposed to the dust on a daily basis should protect themselves with, for example, dust masks. When gluing or painting thermo treated wood, always follow the paint or adhesive manufacturers' specific health and safety instructions.

Handling of residual and discarded products.
When not glued or painted, thermo treated wood waste can be handled like any other untreated wood waste. Thermo treated wood can be burned. Pelletizing and briquetting is possible, if a mixture with normal sawdust is used.

Thermally modified wood research

Research in Europe.

European data and Standards, published as a hand-book, available at Finnish ThermoWood Association website www.thermowood.fi.

The Life Cycle Assessment for ThermoWood (a registered trademark for Finnish wood) was recently completed by Imperial College in London, UK. However, results are not published yet.

The durability results of The center of technical wood and furniture, F – 75012 Paris and the College of mines, F – 42000 available on www.thermottreatedwood.com.

A lot of other research and test results are available on www.thermottreatedwood.com.

Research in North America.

In 1955 Forest Products Laboratory in Madison, Wisconsin in cooperation with University of Wisconsin published report 1621 providing testing data for a so called Staybwood. This report was based on research going back to 1920-30-40th in Germany by Mr. Stamm and Hansen, who later were associated with the University of Wisconsin. For their test the thermo-treated wood was produced utilizing hot-melted metals at temperatures up to 300°C. The main result from this report is a prove that heat-treated wood becomes substantially more dimensionally stable, while losing weight and hardness.

Louisiana Forest Products Laboratory conducted test on the ability of thermo-treated wood to withstand termite attacks in 2002. The softwood, heat-treated with hot oil, showed no additional resistance to termite attacks compared to untreated softwood.

Now the University of Wisconsin Forest Laboratory was deemed as most knowledgeable and having accumulated substantial information as related to heat-treated wood and processes. This lab has a long standing interest in the heat-treated wood.

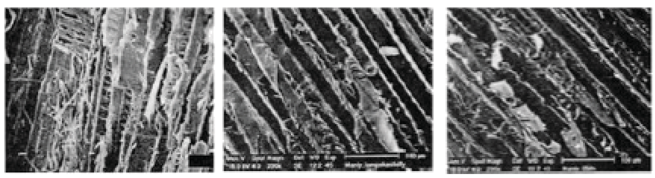
Forintek Canada Corp. was involved in tests for heat-treated wood produced by both Perdure and ThermoWood based processes. The tests were devoted to abrasion resistance, impact and static bending, dimensional stability and resistance to fungal decay.

In 2008 Westwood Corp. has performed a series of experiments on physical properties of Thermo-treated hardwoods and softwoods. The series of structural tests and getting of the US builder codes for thermo-treated decks applications are expected in 2010.

Changes in wood structure and chemical reactions in Thermo-treatment process

Thermo-treatment of wood has an effect on wood's chemical composition is mainly caused by thermo degrading of hemicelluloses and through that on the physical properties of wood. Desired changes start to appear already at about 150 ºC, and the changes continue as the temperature is increased in stages. As a result, swelling and shrinkage due to moisture is decreased, biological durability is improved, colour darkens, several extractives flow from the wood, the wood becomes lighter, equilibrium moisture content decreases, pH decreases, and thermal insulation properties are improved. However, the wood's rigidity and strength properties are also changed.The listed below properties of thermo-treated wood may slightly vary due to the natural difference between lumber species and treatment temperature and time of processing.

The following pictures show how the structure differs between normal untreated pine, thermo-treated pine and 350-years old pine.

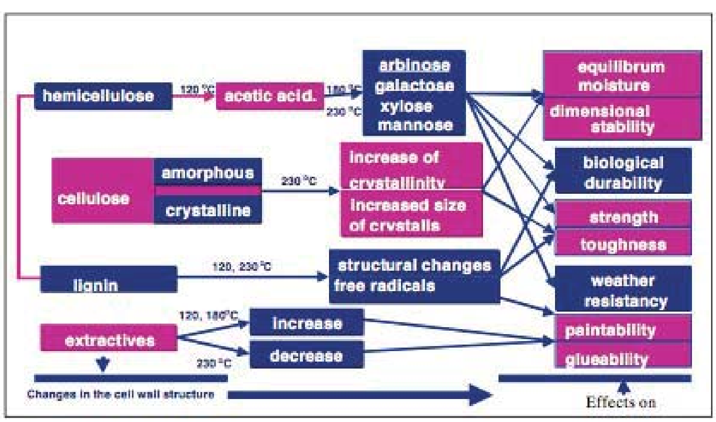


Normal kiln dried Scots pine | Thermally modified Scots pine | 350 year old Scots pine

Why it is happening?

Wood is a three-dimensional polymeric composite made of cellulose, lignin an hemicelluloses, with a small amount of extractives and ashes. A mild pyrolysis (T<500° F) of wood mainly cracks hemicelluloses and begins to modify lignin. By products of hemicelluloses pyrolysis condense and polymerize on lignin chains hence the notion of reticulation (creation of chemical bonds between polymeric chains) which gave its name to "retification" (an abbreviation between reticulatio and torrefaction). These reactions create a new "pseudo-lignin" which is more hydro phobic and rigid than the initial one. An infrared spectroscopy study has indeed revealed a modification of chemical bonds in treated wood: the number of oxygen containing groups (mainly hydroxyl groups) decreased while the number of C= double bonds increased. Cellulose cristallinity does not seem to be affected.

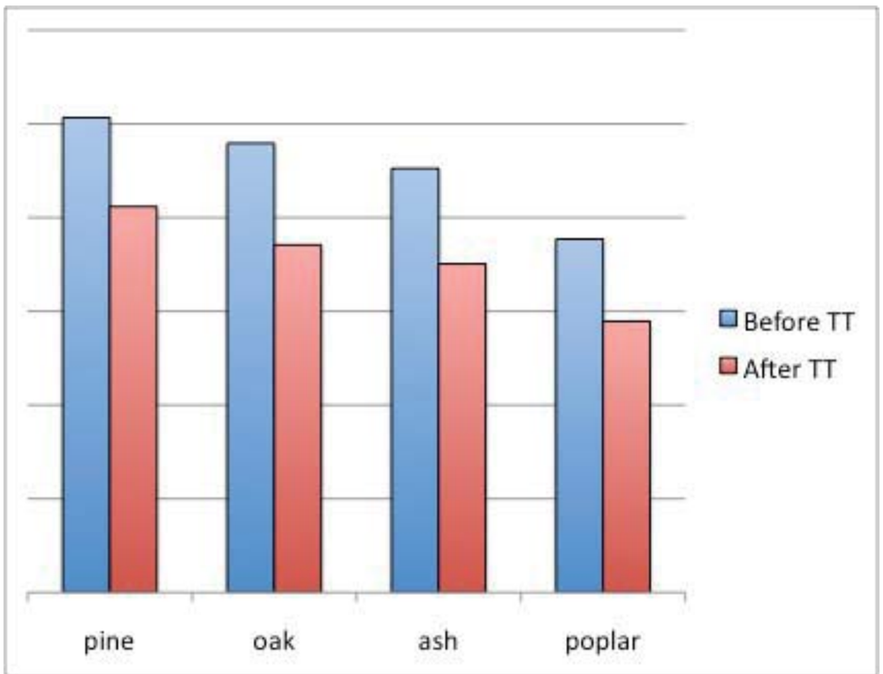
VTT, the Helsinki University of Technology, and the University of Helsinki have published several scientific papers about chemical changes in thermo-treated wood:



Weight loss in Thermo-treatment process

Weight loss factor - 18-23% after thermo-treatment process because of moisture decreases at 2-3 times, and wood elementals emission in thermo-treatment process. The transportation of thermo-treated wood is more cost-efficient than non-treated wood.

# of sample	Species	Before, lb	After, lb	Weight loss, lb	Weight loss in %	Average for species	Weight decrease factor	Density decrease factor
1	pine	23,680	19,567	4,113	17,4%	18,7%	81,3%	84,8%
2	pine	23,170	18,814	4,356	18,8%			
3	pine	28,290	22,742	5,548	19,6%			
4	pine	26,870	21,406	5,464	20,3%			
5	pine	24,650	20,392	4,258	17,3%			
11	oak	25,430	19,774	5,656	22,2%	22,6%	77,4%	83,9%
12	oak	16,125	12,500	3,625	22,5%			
13	oak	32,500	25,095	7,405	22,8%			
14	oak	27,279	20,890	6,389	23,4%			
15	oak	18,510	14,462	4,048	21,9%			
21	ash	20,611	16,306	4,305	20,9%	22,4%	77,6%	82,7%
22	ash	18,079	14,010	4,069	22,5%			
23	ash	16,171	12,554	3,617	22,4%			
24	ash	28,037	21,360	6,677	23,8%			
25	ash	30,211	23,418	6,793	22,5%			
32	poplar	18,110	13,810	4,300	23,7%	23,2%	76,8%	81,5%
33	poplar	28,500	21,824	6,676	23,4%			
34	poplar	16,260	12,548	3,712	22,8%			
35	poplar	12,540	9,700	2,840	22,6%			



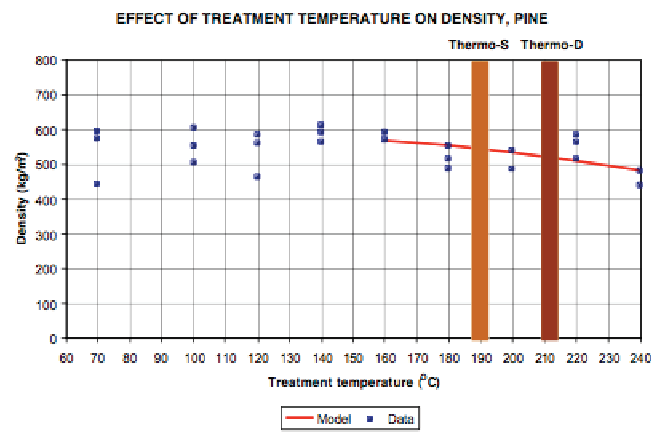
Volume loss (Shrinkage) in Thermo-treatment process

The average shrinkage of wood after thermo-treatment process is 2-3% in width and 1-2% in thickness, so the average volume decrease factor is 5%.

Species	Size, in	Thickness decrease	Width decrease	Volume decrease factor
Pine	1x12	2,1%	2,1%	95,8%
Pine	1x6	1,8%	2,1%	96,1%
Yellow Pine	1x6	1,8%	2,7%	95,5%
Eastern White Pine	2x8	0,9%	1,4%	97,7%
Cedar	1x6	0,7%	2,3%	97,0%
Atlantic White Cedar	1x6	1,2%	1,6%	97,2%
Poplar	1x6	2,1%	3,7%	94,3%
Poplar	5/4x6	2,3%	3,4%	94,4%
Poplar	2x8	2,1%	2,4%	95,6%
Hard Maple	1x6	2,9%	4,6%	92,6%
Hard Maple	2x6	1,7%	2,7%	95,6%
Soft Maple	1x8	2,3%	3,4%	94,4%
Soft Maple	5/4x6	1,4%	3,7%	95,0%
Cherry	1x6	1,9%	3,2%	95,0%
Hickory	1x8	2,4%	3,1%	94,6%
Sawn Red Oak	1x6	4,7%	2,4%	93,0%
Red Oak	1x8	3,2%	4,6%	92,3%
Sawn White Oak	1x6	2,9%	1,9%	95,3%
White Oak	1x6	1,8%	2,8%	95,5%
E.W.P.	1x10	1,6%	2,2%	96,2%
Mahogany	1x8	1,9%	2,2%	95,9%
Ash	1x8	2,6%	3,7%	93,8%
Walnut	1x6	1,1%	1,7%	97,2%

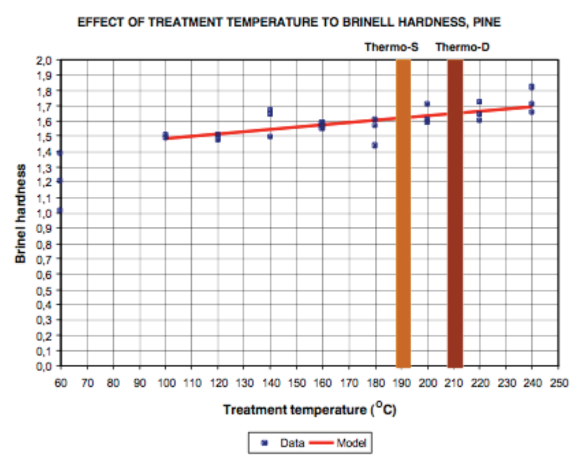
Density loss in Thermo-treatment process

Density is determined by measuring the weight and the dimensions of the sample. Thermo-treated wood has a lower density than untreated wood. As can be seen from the figure below, the density decreases as higher treatment temperatures are used. The average density decrees factor is 10-15% after thermo-treatment process. The strength loss factor is proportional to the density decrease factor, so this data also can be used as a strength loss factor.



Hardness increase in Thermo-treatment process

Brinell hardness has been tested according to prEN 1534. The results show that the hardness increases as the treatment temperature increases. Nevertheless, the relative change is very small (around 10%), it has effect in practice making thermo-treated Oak applicable for commertial areas flooring, as an example.



Based on the research in the US (Westwood – Keim Lumber Company)

Bending Strength decrease in Thermo-treatment process

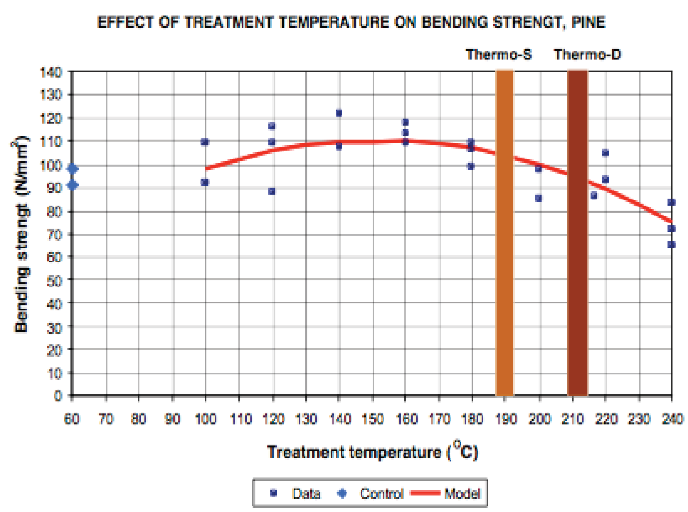
Strength of wood material in general has a strong correlation with density, and Thermo-treated wood has slightly lower density after the treatment. Therefore, it is obvious that Thermo-treated wood in some cases has lower strength values. However, the weight-to-strength ratio can remain practically unchanged. The strength of wood is also highly dependent on the moisture content and its relative level below the grain saturation point.

Impact bending strength (dynamic bending) is less than that of normal kiln-dried timber. It was found that the impact strength was reduced by about 25 per cent.

Shear strength The tests were performed (by VTT) by measuring both radial and tangential directions. It was found that with higher-temperature treatments (at 230 °C for 4 hours) the strength properties were reduced in radial tests from 1 to 25% and in tangential tests form 1 to 40%. However, lower-temperature treatments (at 190 °C) had very little effect.

Splitting strength is reduced by 30-40% and the decrease in strength is greater with treatment at higher temperatures.

Screw holding strength The major impact on screw holding strength was due more to the general variations in wood density than to the heat treatment itself. The study revealed that in lower-densresults were better when smaller, pre-drilled holes were used.



Modulus of Elasticity is not significantly changes in Thermo-treatment process

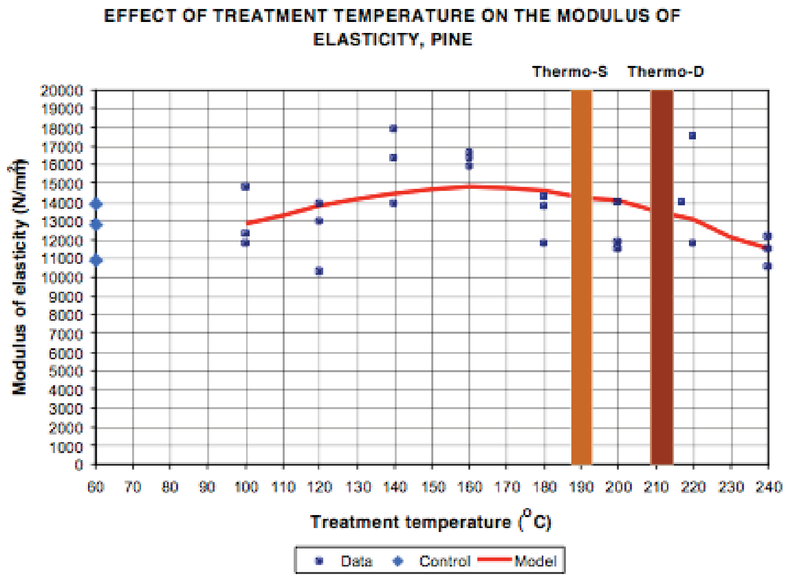


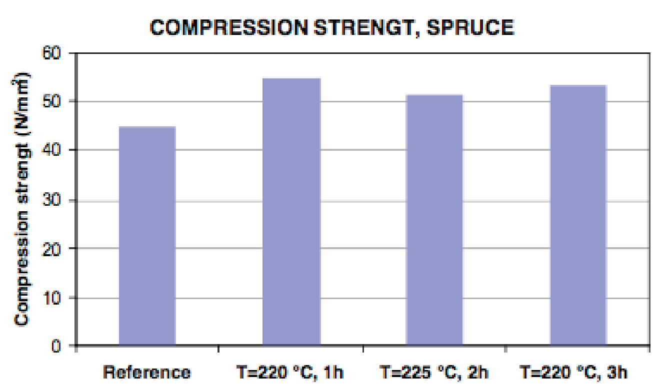
Table 1-4. Bending strength and modulus of elasticity of heat-treated spruce.

Series	width (mm)	height (mm)	length (mm)	RH (%)	density	bending strength 1) N/mm2	modulus of elasticity 1) N/mm2	apparent modulus of elasticity 1) N/mm2
1	38	100	1800	45	425±45	23.0 ± 11.2	11015 ±3142	9495 ±2823
2	38	100	1800	65	392±40	22.5 ± 9.2	12326 ± 1681	11494 ±1280
3	100	38	1800	45	392±25	19.0 ± 5.4	10486 ±1649	9537 ± 1705
4	100	38	1800	65	397±17	27.9 ± 5.9	11913 ±1422	11230 ± 1224

1) mean value and standard deviation

Compression strength is not changes in Thermo-treatment process

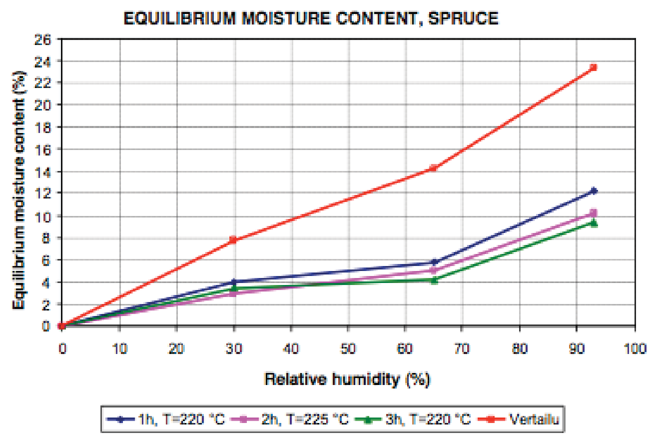
Actually, the results indicate that the compression strength values were better than with untreated wood even when a higher treatment temperature was used. Tests show that when the maximum compression load was achieved, the pieces broke into smaller sections but didn't buckle like normal kiln-dried timber. This revealed clearly that heat-treated timber is not as elastic as normally kiln- dried timber.



Based on the research in Europe (VTT, Finland)

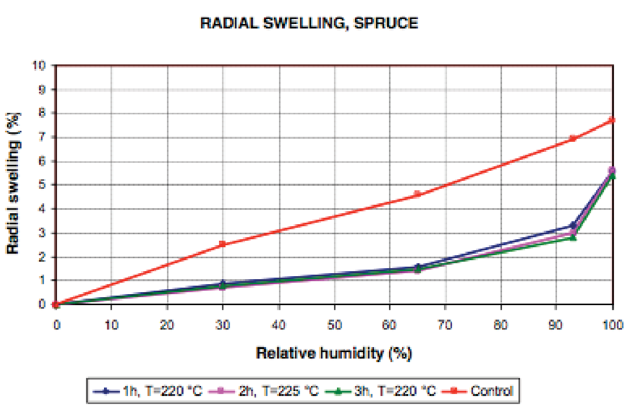
Equilibrium moisture content in Thermo-treated wood is lower by 50% when compared with untreated wood

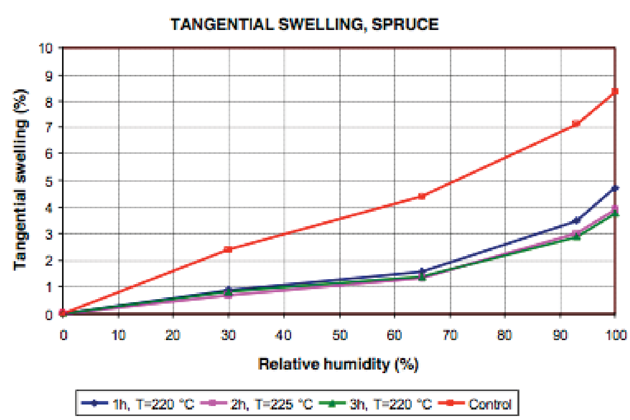
The difference in wood moisture values is higher when the relative humidity is higher.



Swelling and shrinkage due to moisture in Thermo-treated wood reduced in 2-3 times for softwoods and in 5-10 times for hardwoods when compared with untreated wood

The important factor also, that unlike timber in general, thermo-treated wood does not feature drying stress. This is a clear advantage, seen when, for example, splitting the material and manufacturing carpentry products.

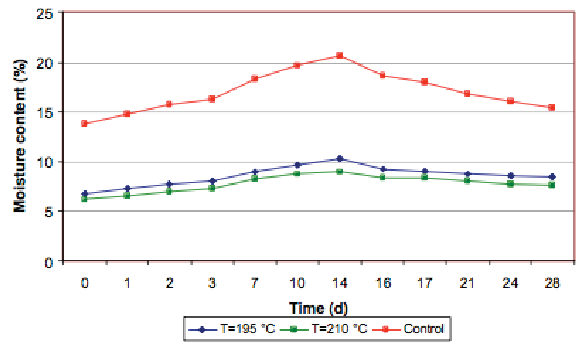




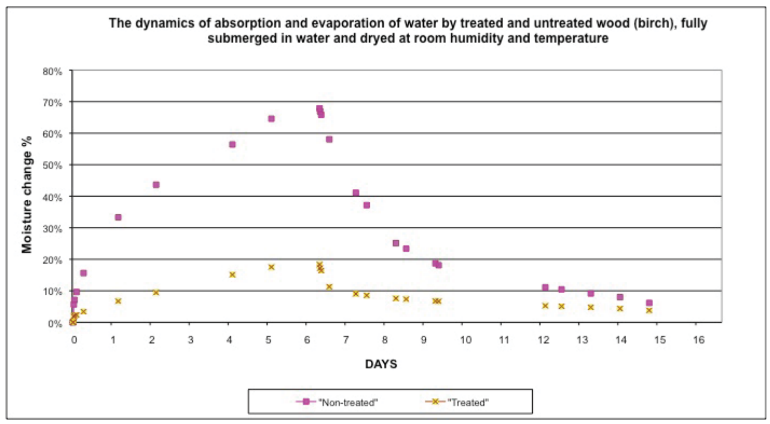
Based on the research in Europe (VTT, Finland)

Water permeability of Thermo-treated wood is reduced in 2 times for softwoods and in 5 times for hardwoods when compared with untreated wood

Softwood experiment according to EN927-4. Samples were dipped in water and then kept in a room with a relative humidity of 65% and a temperature of 20 ° C. The samples were periodically weighed over a period of 9 days.



Hardwood experiment. Samples were dipped in water and kept in over a period of 7 days.



Thermal conductivity of Thermo-treated wood is reduced by 20-30% when compared with untreated wood

Therefore, Thermo-treated wood is well-suited for applications like outer doors, cladding, windows, and saunas. According to the VTT tests, the thermal conductivity 10 of Thermo-D class ThermoWood is 0.099 W/(m K). The corresponding value for untreated timber according to Section C4 of the Finnish building code is 0.12 W/(m K).

Table 2-4. Thermal conductivity

Dimension (mm)	Treatment time at 230 °C (h)	Weight loss (%)	Density (kg/m^3)	Moisture content (%)	Thermal conductivity λ_{10} W/mK
			Pine		
25 x 125	3	8,7	525	4,5	0,107
25 x 125	5	12,1	474	3,6	0,101
	0		505		0,130
			Spruce		
22 x 100	3	5,8	445	5,5	0,097
22 x 100	5	9,3	405	4,4	0,082
	0		432		0,110

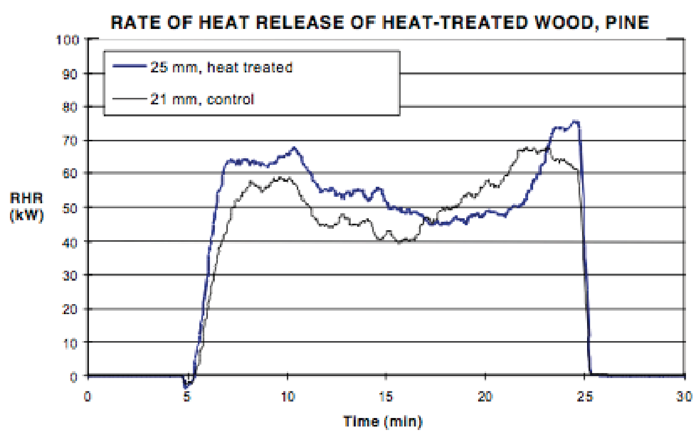
Based on the research in Europe (VTT, Finland) and in the US (Westwood)

Fire resistance of Thermo-treated wood does not differ significantly from normal wood when it comes to fire safety

Thermo-treated wood is in fire class D. Below are RHR (Rate of Heat Release) and SBI (Single Burning Item) test results for thermo-treated pine. The ignition time tested according to ISO 5660 decreased 32% for pine, and spruce samples showed no difference.

Tests carried according to the NF B 52501 standard classified samples in Class M3. The tests indicate that the fire resistance of thermo-treated wood has to be considered to be the same as that of untreated wood of corresponding species.

Test to British Standard, BS 476 Part 7, shows the thermo-treated wood had a clearly shorter ignition time but was better than the normally dried softwoods in terms of heat and smoke release.



Product	Thick-ness (mm)	FIGRA (W/s)	THR_{600s} (MJ)	SMOGRA (m^2/s^2)	TSP_{600s} (m^2)
Spruce	18	419	18.0	4	36.3
Pine (heat-treated)	25	581	32.8	6	62.5
Pine	21	321	23.2	3	15.0
Pine (with cavity of 22 mm)	21	329	22.3	4	35.5
Pine	15	361	26.6	4	17.5
Pine	45	587	23.9	12	54.4
Spruce (tongue and groove), vertical	15	452	17.0	3	34.0
Spruce (tongue and groove), horizontal	15	494	18.4	4	50.0
Plywood (spruce)	12	596	15.8	3	45.0
Plywood (pine surface)	12	437	16.6	1	21.0

Based on the research in Europe (VTT, Finland)

Biological durability of Thermo-treated wood is increased significantly (by 25 times) when compared with untreated wood

The tests were carried out in accordance with the EN 113 standard, with a 16-week decay time. And according to ENV 807, with a 8, 16, 24, and 32 weeks. The test fungi were *Coniophora puteana and Poria placenta* since these are regarded as the most common and problematic fungi.

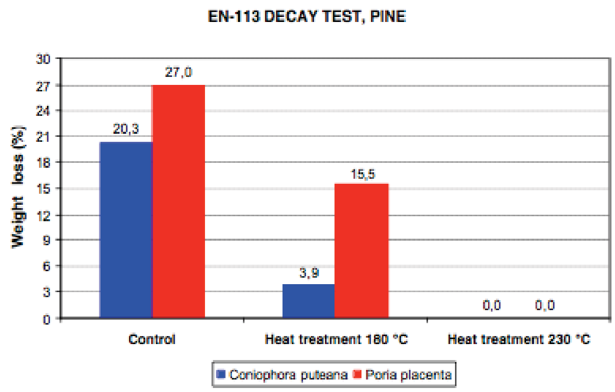
The French research confirmed that the durability in thermo-treatment process is much better increased for hardwoods than for softwoods.

Species of wood	Durability class[1,2]		Equilibrium moisture content in climate 20°C/65%[3]	
	Not thermally treated	Thermally treated	Not thermally treated	Thermally treated
TEAK	1	---	10,5	---
BEECH	5	1	11,5	4,0
ASH	5	1	11,0	4,0
OAK	2	No scientific results up to now	13,0	4,8

[1] Division of durability classes according to DIN 350-2
[2] Species of wood classified in accordance with DIN 250-2

Class	Definition	Life expectancy in moderate climate	Life expectancy in tropical climate
1	Very durable	Over 25 years	Over 15 years
2	Durable	15 to 25 years	10 to 15 years
3	Moderately durable	10 to 15 years	5 to 10 years
4	Low durability	5 to 10 years	2 to 5 years
5	Not durable	2 to 5 years	Less than 2 years

[3] approximate values



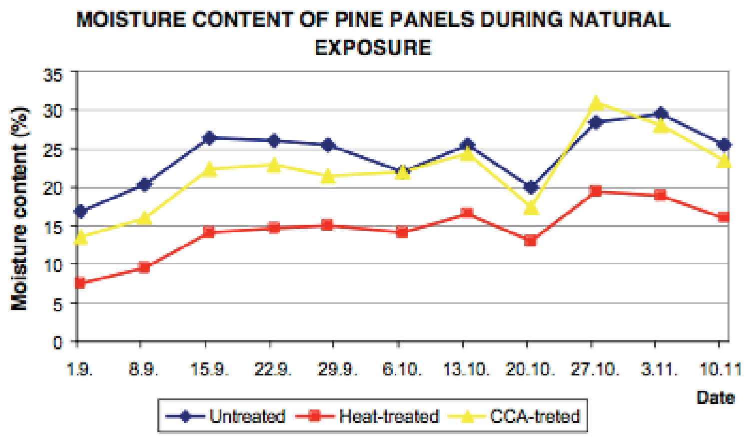
	Untreated Wood		Retified Wood	
	Weigh Loss (EN 113)	Classification (EN 350-1)	Weigh Loss (EN 113)	Classification (EN 350-1)
White Fir	18,0%	4	2,1%	1
Scots Pine	21,7%	5	4,1%	2
Maritime Pine	21,2%	5	5,9%	2
Poplar	26,8%	5	1,1%	1

	Treatment 1				Treatment 2			
	Retified samples		Reference samples		Retified samples		Reference samples	
	PM%	H%	PM%	H%	PM%	H%	PM%	H%
Coniophora Puteana	0.4	29	31.8	117	0.2	35	46.2	142
Gloephyllum trabeum	0.4	30	37.7	61	0.3	54	35	73
Coriolus versicolor	0.1	36	40.7	156	0.0	74	37.9	187

Based on the research in Europe (VTT, Finland; Technical Wood and Furniture Centre, France)

Rain exposure of Thermo-treated wood is showed two tomes lower moisture content when compared with untreated wood

This difference remained after five years' exposure. The following diagram describes the moisture content development in natural weather conditions of untreated wood, Thermo-treated pine, and CCA-treated wood. The difference for thermo-treated hardwood is greater than for thermo-treated softwood.



Sun exposure of Thermo-treated wood shows no significant difference to resist UV when compared with untreated wood

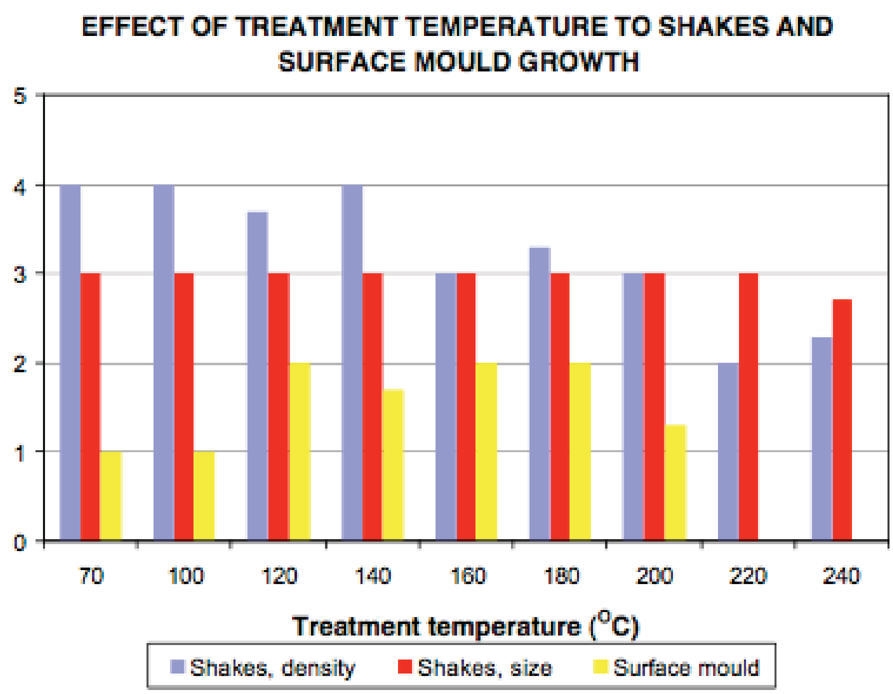
The color changes over a period of time from the original brown appearance to a grey weathered color when exposed to direct sunlight. The original Thermo-treated wood color can be preserved with pigmented or UV-protective preservatives.

Two examples of ThermoWood cladding after three years weather exposure with and without surface coatings.

Based on the research in Europe (VTT, Finland)

Sun exposure of Thermo-treated wood shows the increased ability to resist surface shakes when compared with untreated wood

The ultraviolet radiation causes also small surface shakes to occur on uncoated surface when exposed. Levels of surface shakes in Thermo-treated wood did show signs of improvement over the untreated control material when higher temperatures were used. Surface treatment is therefore highly recommended.



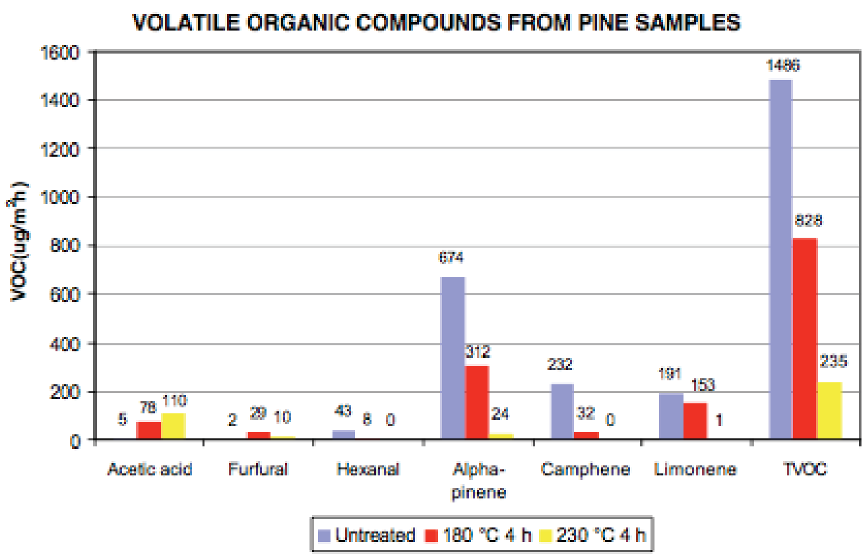
The shakes were graded as follows:
Size (0–5):
0 no shakes
1 the shake is seen with the loop, 10 times enlargement
2 the shake is just seen by the eye 3 the shake is clearly detectable
4 shakes where the width is under 1 mm
5 large shakes, with width over 1 mm
Density (0–5):
1 one shake
5 the surface is full of shakes

Based on the research in Europe (VTT, Finland)

Emissions of Thermo-treated wood is scientifically lower when compared with untreated wood

The emission measurements were carried out according to the KET 3300495 test method. Untreated pine showed the largest quantity of volatile organic compounds, 1486 µg/m2h. The majority of this consisted of terpenes, and significant amounts of alpha-pinene, camphene, and limonene were found. Untreated pine contained hexanal and small amounts of furfural and acetic acid too. The total emission for heat-treated pine treated at 180 °C was 828 µg/m2h. The sample contained terpenes, furfurals, hexanal, and acetic acid. The total emission of heat-treated pine treated at 230 °C was the lowest, at 235 µg/m2h. This consisted mostly of acetic acid (110 µg/m2h). This sample contained only small amounts of terpenes.

The smoke-like smell of thermo-treated wood most likely comes from furfural. The smell has been found to disappear over time, and when surface treatments are applied the smell is removed.



<u>Emissions in Thermo-treatment process are scientifically lower when compared with environmental regulations</u>

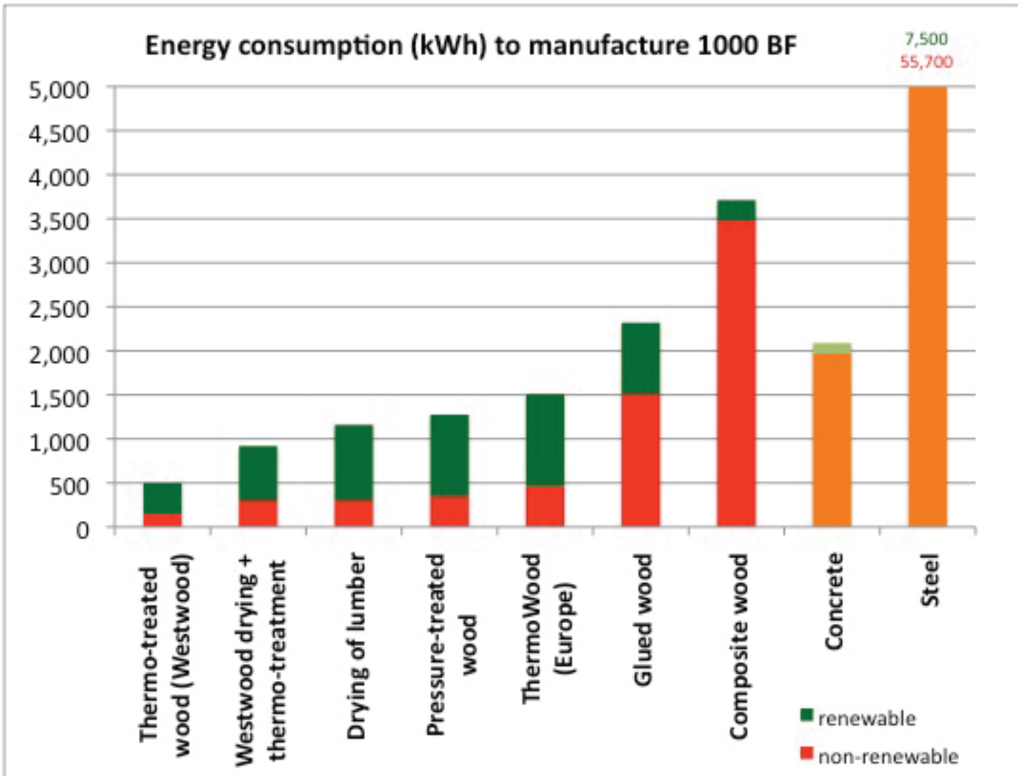
WATER	Measurement unit	Concentration
Smell	Smell of wood, degrees	20
Turbidity	g/cub.m.	1,5
Color	degrees	20
PH	units	7,5
Ammonia	g/cub.m.	1,8
Nitrites	g/cub.m.	0,135
Nitrates	g/cub.m.	1,5
Hard water	g-eqv/cub.m	5
Chlorides	g/cub.m.	11,04
Sulphates	g/cub.m.	13,2

AIR	Measurement unit	Concentration
Phenol	mg/cub.m.	0,10
Formaldehyde	mg/cub.m.	0,15
Carbon oxide	mg/cub.m.	0,52

Based on the research in Europe (VTT, Finland) and in the US (Westwood)

Energy consumption to manufacture Westwood Thermo-treated wood when compared with untreated wood and other materials

Westwood thermo-treatment process (even the combination of KD and thermo-treatment) is the most energy-efficient when compared with regular KD process, European thermo-treatment technologies and the other materials.



Based on the research in Europe (VTT, Finland) and in the US (Westwood)