Drying wood
- small scale industrial production

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Drying is a key sawmill process

- Drying possibly the most critical process for the profitability of a sawmills
  - great impact on final product value
  - large investment in equipment
  - labour intensive
- Swedish sawmill production higher than 17 Million m3/year
  - requires more than 5 TWh thermal energy
  - drying kilns use approximately 50 % of sawmill electricity consumption

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Why kiln dry wood?

- Fast process to reach Moisture Content suitable for further processing and final use
- Water content in growing tree very high
  - wet wood will be damaged by mould, bluestain, and rot
- Controlled drying reduce distorsions and drying damages
  - conditioning to reduce moisture gradient and stresses possible in kiln
- Planing, gluing, impregnation, and painting normally requires dry wood
- Dry wood weigh less and is cheaper to transport
  - and kiln drying reduce need for large stores of air dried wood
- Dry wood has better strength properties

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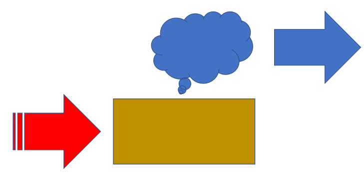
The basic principle of wood drying

1) Add energy

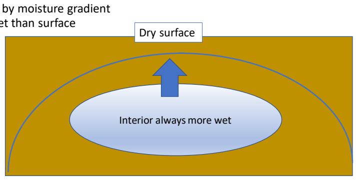
- 2) Moisture evaporates
- 3) Remove the moisture



- Wood drying is based on energy trasfer to the wood

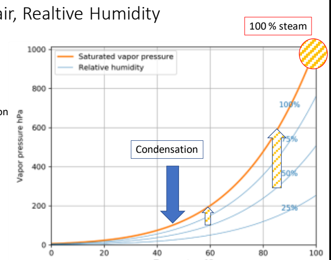
The basic principle of wood drying

- Moisture evaporates from surface of wood
- Moisture flows out from interior to surface
- Moisture transport driven by moisture gradient
  - interior must be more wet than surface
- Fast drying means high moisture gradient
- High gradient means risk for checking



Moisture in air, Realtive Humidity

- Warm air can carry more moisture than cold air
  - dew falls in the evening as temperature drops
  - 100 % water vapour possible at 1013 mBar
- Vapour pressure above saturation lead to condesation
  - higher pressures really not happening
- Saturated steam cannot take up moisture
  - saturated steam cannot dry the wood
- Drying can occur in dry air
  - vapour pressure is below saturation
- Drying force depends on RH and temperature



From Vaisala, homepage, September 2020.

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Dry bulb temperature and wet bulb temperature

- Drying climate is usually measured by one dry thermometer together with one soaked in water
- The dry thermometer is called the ”dry bulb”
  - shows the actual temperature in the drying kiln
- The ”wet bulb” temperature shows the dew point
  - shows the temperature where water vapour condenses
  - or saturation temperature
- The greater difference between dry bulb and wet bulb, the stronger drying force is applied

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Moisture in the growing tree

- Cone on top of cone
  - ”growth ring” slightly misleading
- Trees designed to transport liquids up and down
  - much slower transport sideways
- Branches and knots
  - as tree grows, lower branches dies
  - knot pattern varies with height
- Heartwood and sapwood
  - juvenile wood
  - density profile
- Impact on wood drying
  - heartwood dryer than sapwood
  - more sapwood higher up in tree
  - drying speed different

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Moisture in the sawn lumber

- Initial MC depends greatly on heartwood content
  - sideboards higher MC than planks
- Density important parameter
  - lower possible maximum MC at high density
  - influences drying speed
- Knots increase drying speed
  - acts as ”chimneys” for moisture transport

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Measuring Moisture Content (MC) of wood

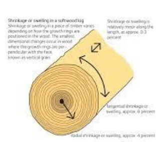
Moisture Content MC is defined as: $MC\ (\%) = \dfrac{\text{Mass of water}}{\text{Dry weight of wood}}$

Practical formula: $MC\ (\%) = 100 \times \dfrac{(\text{weight of wet wood} - \text{weight of dry wood})}{\text{weight of dry wood}}$

- Moisture Content is not an exact value
  - terpenes and other volatile compounds influence measurement
- Electrical MC measurement can never provide an accurate value
  - measurement depends on density, temperature, grain angle and so on...
  - expect shown value to be +/- 2 % from true value
- Laws of physics applies to all existing commercial systems
  - disregarding what the sales person tells you

Shrinking and swelling

- Different shringking in different directions
  - tangential shrinking 2 times higher than radial
  - tangential shringking 20 times longitudinal
  - lead to distorsions, stresses, and checking
- Cupping as growth rings ”straightened”
- Further drying deformations
  - twist
  - crook
  - bow
- Production process designed to reduce difficulties
  - sawing patterns
  - proper stacking
  - loading
  - drying schedule



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From Swedish Wood homepage

Different drying methods

- Air drying
- Convective kiln drying
- Vacuum drying
- RF and Microwave drying

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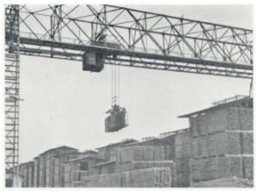
Air drying

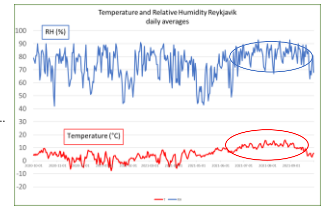
- The original way to dry wood
  - sometimes called ”natural drying”
- Obvious benefits
  - limited need of equipment
  - requires very little energy input
- Drawbacks identified early:
  - depends on weather, unpredictable
  - severe degrade and loss of value
  - not possible during winter
  - time consuming
  - entire production ready at the same time
  - requires large storage of wood
  - cannot dry below shipping dry
- Most wood needs to be kiln dried anyhow
- Commonly used to pre dry species prone to collapse



In the large open timber yard, the drying stacks are lifted with by a bridge crane that takes care of all loading and unloading.
From Svensk skog och skogsindustri, 1956

Air drying in Iceland?

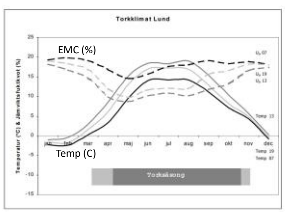
- Short period warm enough
  - three months ?
- High RH during warm period
  - severe risk for mould
- Air drying seems not really suitable...
  - but does theory match reality ?



2020-2021 data supplied by Sibylle von Löwis, Veðurstofa Íslands

Air drying in Denmark?

- Longer drying season than Iceland (!)
  - seven months ?
- Lower RH during warm period
  - reduced risk for mould
  - increased risk for checking
- Air drying could be an option
  - but does theory match reality ?
- Is air drying used ?
  - if so, experience ?

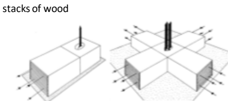


Air drying climate in Lund, southern Sweden. From Stenudd.

Forced air drying

- Fan tower forces air through stack
  - possible to reduce checking
  - reduce risk for mould growth
- Developed by the legendary Thomas Thomassen
  - increase drying speed and
  - allows certain control of drying process
- Low cost solution
  - low investment
  - no heating required
  - cost to run fans can be high
  - requires skillful manual control
- One fan tower can support several stacks of wood
- Use clever loading and unloading
  - improve drying quality
  - increase capacity

From Stenudd, Stefan: Forcerad virkestorkning

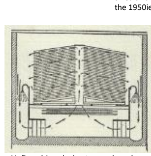


From Stenudd, Stefan: Forcerad virkestorkning

The origins of artificial or kiln drying

- Artificial drying in ancient times
  - smoke drying possibly in Greece 7th century BC
  - clearly used in China 2nd century BC
  - definitively used in Rome 1st century AD
  - used in Europe and USA still after WW2
- Systematic research started in mid 18th century
  - Henri-Louis Duhamel du Monceau, France 1767
  - First kiln with forced air ventilation, USA 1844
  - Sturtemant, first continuous kilns approx. 1920
  - Harry D. Tiemann wrote the book on it, USA 1915
  - Climate control systems on market by 1926 in USA
- Centurys before industrial breakthrough
  - lack of efficient fans main obstacle

Swedish smoke kiln for grain. Still in use in the 1950ies. Arvslindan, Dalarna, Sweden.

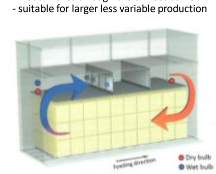


Air flow driven by heaters and condensers.
From Tiemann, 1917

Batch kilns and continuous kilns

- Batch kilns
  - dries one batch at a time
  - wood stands still
  - climate changed as drying progresses
  - suitable for smaller or variable production
- Continuous kilns
  - new wood stacks added at regular intervals
  - climate fixed during process
  - wood moves through the climate curve
  - suitable for larger less variable production

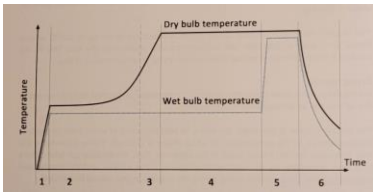
From Morén, Basics of wood drying



From Morén, Basics of wood drying

The main phases of the drying schedule

- Heating phase 1
- Capillary drying phase 2
- Transition phase 3
- Diffusion drying phase 4
- Konditioning 5
- Cooling 6



From Morén, Basics of wood drying

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The heating phase

- Heating the wood up to temperature where drying can start
- Critical that drying is prevented or minimized
  - if surface of cold wood dries, severe checking can result
- Critical that heating is fast enough
  - wood will pass through temperatures ideal for mold growth
- Combination of heating methods used
  - use saturated steam (ideal)
  - use the heating coils to warm the air
  - balance hot air by water spraying

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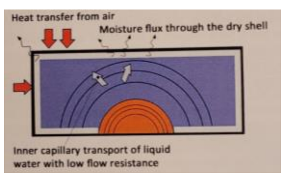
The capillary phase

- Sapwood still almost saturated with water
  - water can flow by capillary forces to surface
- Drying controlled by heat transfer to the wood
  - if air vents are big enough
- Heartwood starts at lower moisture content
  - does not show a real capillary phase
- Dry surface zone develops as surface wood dries
  -



From Morén, Basics of wood drying

- Need to balance between capillary (sapwood) and not capillary (heartwood)

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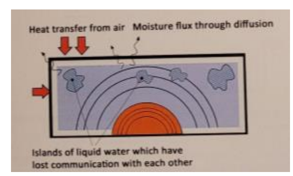
The transition phase

- As wood dries, the capillary flow paths are broken
  - volumes with liquid water no longer connected
  - drying rate drops dramatically
- Evaporation zone sinks down into the wood
- Surface wood starts to dry and shrink
  - building tension stresses, risk for checking
- Need to slow down drying process
  - keep surface moist to reduce stresses
  - increase temperature to soften wood



From Morén, Basics of wood drying

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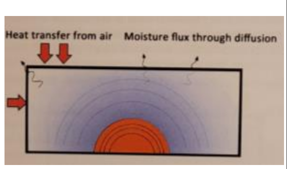
The diffusion phase

- Water can no longer flow by capillary forces to surface
  - complex new transport pattern takes over
- Most water bound to cell walls
  - moisture transport driven by moisture gradient, the difference in moisture between inner parts and surface
- Drying speed is controlled by the gradient:
  - fast drying needs large difference in moisture
  - smaller difference leads to slower drying
- The surface will be drier than the inner parts after drying



From Morén, Basics of wood drying

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The conditioning phase

- Wood will always have a moisture gradient after drying
  - surface drier than interior
- Built in drying stresses can be severe after drying
  - stresses need to be reduced if wood shall be further processed
- Remoistening of surface to even out gradient
  - steam or water spraying used to increase humidity
- Rapid heating together with remoistening releases stresses
- Gradient and stresses almost eliminated by proper conditioning

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The cooling phase

- Surface dries extremely fast if hot wood is taken out into cold air
  - rapid shrinking of outermost layers
- Micro- cracks develop in surface
  - can cause difficuties in surface coating
- Temperature difference between kiln and exterior
  - high drying temperatures in winter risky
- Adding controlled cooling phase to eliminate risk

Heat consumption in drying kilns

- Swedish sawmills use 5 TWh thermal energy to dry 17 Million m3/year
  - systems once developed to cool boilers burning sawmill waste
  - now sawmill waste has become a valuable product
- Ventilation batch kiln requires at least twice the theoretical heat of evaporation
  - heat of evaporation + heating cold air used for ventilation
  - rule of thumb...
- Continuous kilns more energy efficient
  - allows economical heat recovery
  - condensing at intake end "Gratis" heat recovery
  - total heat consumption can be lower than heat of evaporation
- Closed drying systems to reduce heat consumption
  - condensating kilns
  - vacuum kilns
  - possible alternative if there is no boiler at the site

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Electricity consumption in dryng kilns

- Fans consume roughly 50 % of all electricity used in sawmills
  - more economical use quick way to reduce costs
- Fan speed requirements differ between drying stages
  - high speed needed in capillary phase when evaporation is high
  - speed kan be reduced in diffusion phase as drying is slower
- Key issue is to maintain climate control throughout the batch
  - low air flow in early stages will slow production without quality gain
  - high air speed in late stages will increase cost with limited improvement of speed and quality
- Frequence control dominating in newer kilns
  - two speed motors still common in older kilns

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Smaller drying kilns

- Buy a machine or build a kiln?
  - influence financing
- Boiler or not?
  - closed systems greatly reduce heat consumption
  - condensing kilns
  - vacuum kilns
- Container kilns suitable for small operations
  - roughly 500 m3/year capacity (50 mm, 46 weeks)
- Larger operations need larger kilns

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Container kiln

- Numerous products on the market
- Reasonably low cost alternative
- Machine, not building
- Could be a good option for smaller production
  - kiln capacity approximately 500 m3/year
- The Devil hides in the details
  - low cost control systems and hardware
  - caution needed before investing

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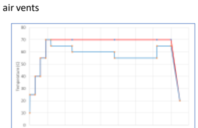
Build your own kiln?

- Numerous drawings on internet
  - mainly hobby- kilns
- Low cost alternative that allows for controlled drying
- Free choice of size and construction
  - container
  - existing building
  - purpose built
- Decide on technical level
  - manual control of valves and air vents
  - regulators for temperatures
  - automated control system
- Balance speed and quality



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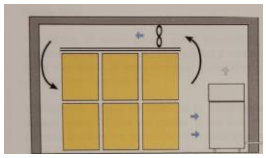
Dehumidification kilns

- Alternative primarily if sawmill has no boiler
  - increased need for electricity
- Limited heating capacity
  - long heating phase
  - limited drying capacity in capillary phase
  - difficult reach temperatures above 60 C
- Common to air dry before kilning
  - kilns most suitable for diffusion phase
- Adding external oilburner
  - shorten heating phase
  - allow for efficient conditioning



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Vacuum kiln

- Mainly used for hardwoods
  - eliminate risk for mould, no oxygen
  - reduce risk for collapse
  - extremely fast for certain difficult species
- Alternative if no boiler
  - small oil burned can support the kiln
- Difficult to control final moisture content
  - high variation if dried above 12 % target MC
  - most suitable for indoor carpentry 6-8 % target
- High investment but counts as a machine

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Examples of drying mistakes

1) Mould growth
- wood stored too long before drying in humid conditions
- to low temperature in kiln

2) Severe checking
- wood stored in dry conditions before kiln drying
- drying during heating phase
- to hard drying schedule in transition phase

3) Deformations
- poor stacking, wood not supported
- top layers exposed to high air stream without loading

4) High variation in final moisture content
- irregular air flow
- too short diffusion drying phase

5) Deformations shown in storage after drying
- improper conditioning
- failed to hit target moisture content

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What to do and what not to do

- Wood must not be exposed to uncontrolled pre drying
  - windy and sunny day may lead to 25 % checking in a few hours
  - if storage is needed, protect wood against sun
  - if necessary, spray water on stacks to keep them wet
- Mould must not be allowed to grow prior to drying
  - late summer and early autumn critical periods
- Drying shall never take place during heating phase
- Drying kilns shall if possible control the sawmill production
  - no use sawing material that is destroyed prior to drying

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Controlling the quality to improve process

- Key to profitable drying
  - eliminate drying checks
  - hit target MC, do not overdry!
  - increase drying capacity, faster with higher quality
  - optimize fan speed, reduce cost of electricity
  - requires many hours of manual work
- Yield in final quality does not tell the whole story
  - does not show causes of degrade
  - goive little information on how to improve yield
  - provides warning sign if something is going wrong
- Need to look at the whole picture
  - wood value
  - personnel
  - equipment

Klamparriksdag, calibrating visual sorting between all graders. Ala sawmill 1980-ies. Photo Christer Forslund

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Thank you for your attention

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