CLT by Stora Enso

Technical brochure

United States & Canada

THE RENEWABLE MATERIALS COMPANY

storaenso

Stora Enso
The renewable materials company

Part of the bioeconomy, Stora Enso is a leading provider of renewable solutions in packaging, biomaterials, wood construction products, and paper across global markets.

We believe everything made from fossil-based materials today can be made from a tree tomorrow. Our materials are renewable, reusable and recyclable, and form the building blocks for a range of innovative solutions that can help replace products based on fossil fuels and other non-renewable materials.

Because wood captures and stores carbon, our products offer a truly sustainable means of combating climate change.

Stora Enso products are entirely made from renewable wood, sourced from sustainably managed forests. The wood supply chains that source Stora Enso's Wood Products units are covered by a third-party certified wood traceability system.

Contents

This brochure is a summarized version of technical information and documentation available directly from Stora Enso. Detailed information, including information about references to sources, is available by request.

See also:
storaenso.com/woodproducts/clt
Stora Enso Oyj accepts no liability for the completeness or accuracy of the information herein contained.

1. Sustainability

How we work

Sustainability is integral to Stora Enso's business strategy—it is at the core of what we do. Building on our strong foundation of conducting our everyday business in a responsible manner, in 2021 we embarked on a bold journey to offer 100% regenerative products and solutions by 2050. Being regenerative means shifting our sustainability goals from minimizing negative environmental impacts to becoming a net positive contributor within the focus areas of climate, circularity, and biodiversity.

Climate benefits of wood

Growing trees naturally remove CO_2 from the atmosphere. When these trees are harvested and manufactured into long-lived forest products, such as CLT, the wood provides long-term carbon storage. Carbon mitigation is further increased when those wood products replace carbon-intensive materials, as typically occurs.

Our renewable wood products help future proof buildings against increasingly stringent emissions regulations and tenant/owner requirements, while contributing to a climate change solution.

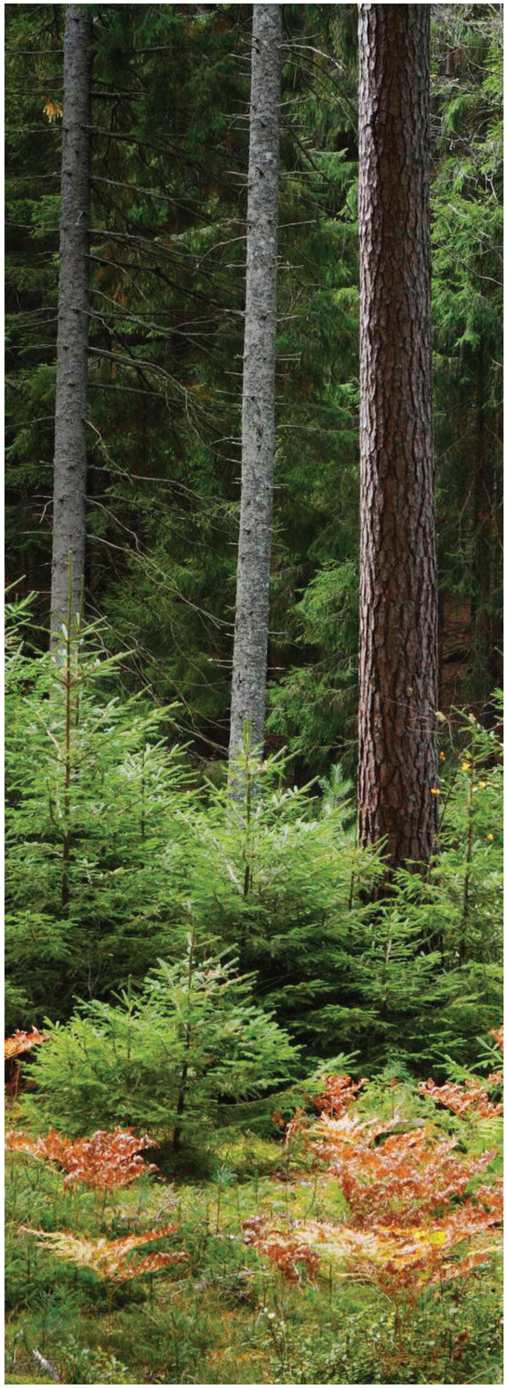
Sustainable forestry

The timber for Stora Enso's wood products originates from sustainably managed European forests, which continuously increase by both area and volume. One of the world's largest private forest owners, Stora Enso uses various tools to ensure sustainable forest management and to secure due diligence of the origin of all the wood we use. These tools include third-party forest certification systems, such as the FSC® - Forest Stewardship Council (C125195) and the PEFC™ - Programme for the Endorsement of Forest Certification.

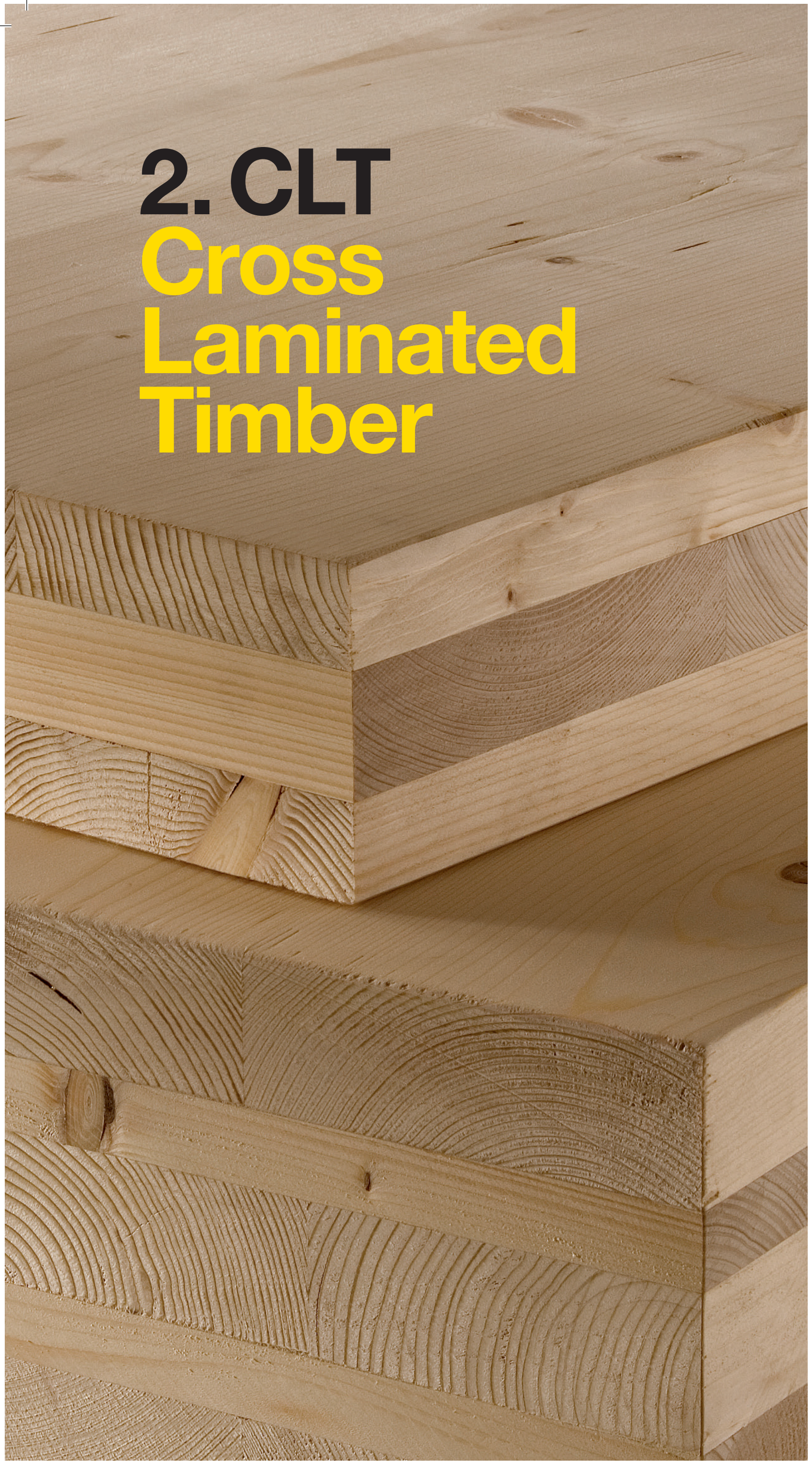
We are an active member of leading forestry initiatives, including the World Business Council for Sustainable Development's Forest Solutions Group, WWF's Forests Forward platform and The Forests Dialogue.

Learn more

Read more about Stora Enso's sustainability work at https://www.storaenso.com/en/sustainability. Environmental product declarations (EPDs) can be found at https://www.storaenso.com/woodproducts/clt.



2. CLT Cross Laminated Timber



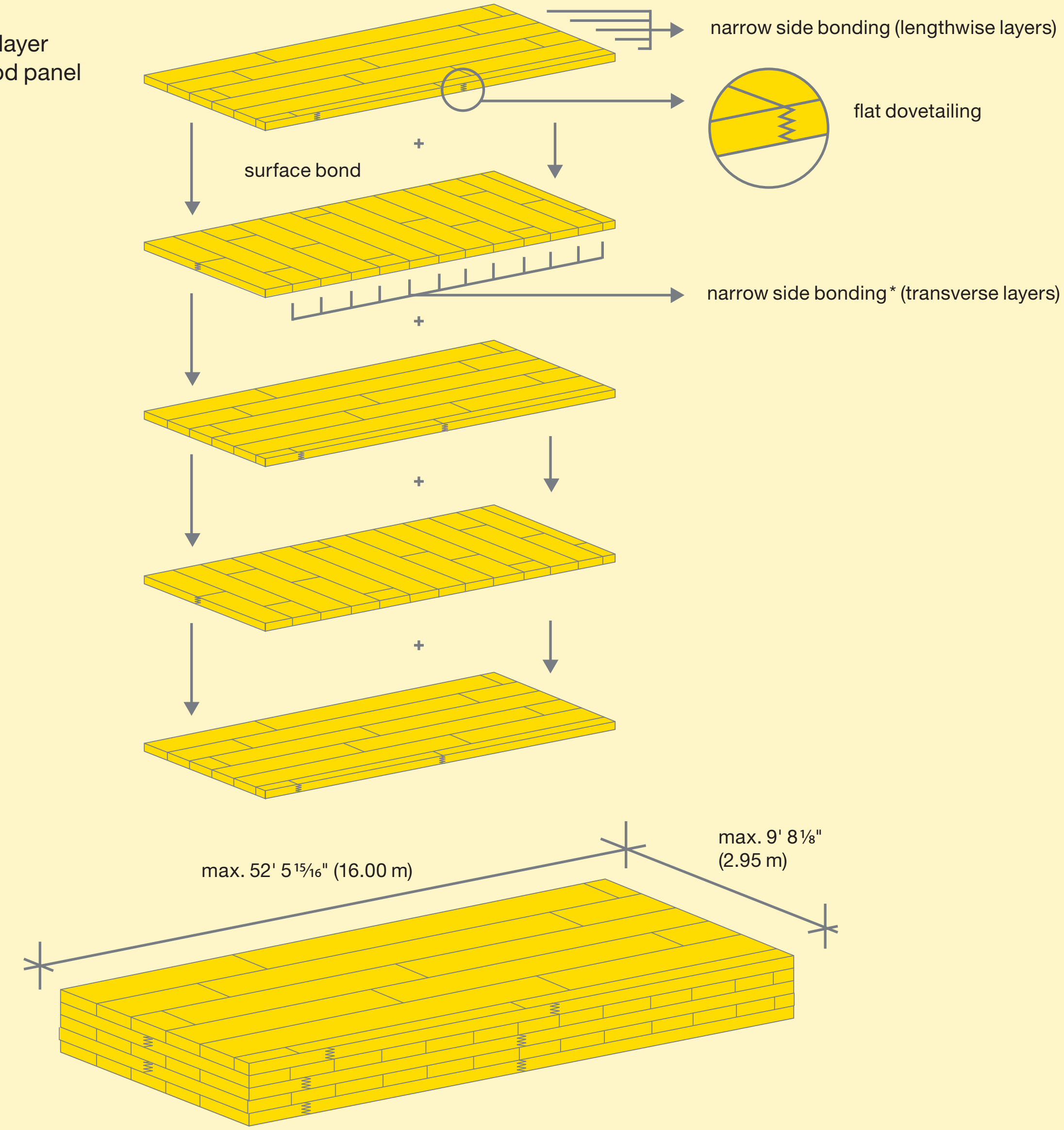
Key data

Application	Structural elements for walls, floors, and roofs
Maximum element dimensions	Length: 52' 5 15/16" (16 m) / Width: 9' 8 1/8"" (2.95 m) / Thickness: 1' 5/8" (320 mm)
Invoiced widths	7' 4 9/16" (2.25 m) / 8' 7/16" (2.45 m) / 9' 1/4" (2.75 m) / 9' 8 1/8" (2.95 m)
Panel lay-up	3, 5, 7 or more layers depending on structural design requirements
Wood species	European spruce (pine, fir, stone pine/larch and other wood types on request)
Moisture content	12% +/-2% on delivery
Adhesive	Formaldehyde-free PUR adhesive for finger jointing and surface bonding, approved for load-bearing and non-load-bearing components indoors and outdoors conforming to ANSI/APA PRG 320; Formaldehyde-free EPI adhesive for narrow side bonding
Surface quality	Non-visual quality (NVI), Industrial visual quality (IVI) and Visual quality (VI); the surfaces are always sanded on both faces
Weight	35 lb/ft^3 (5.0 kN/m^3) for structural analysis For determining transport weight: approx. 30 lb/ft^3
Thermal conductivity	0.07 BTU/(h·ft·°F) [0.12 W/(m.K)]
Air tightness	CLT panels are made up of at least three layers of single-layer panels and are therefore extremely air-tight.

Panel design

CLT solid wood panels are made up of at least three layers of bonded single-layer panels arranged at right angles to one another. From five layers, CLT can also include middle layers (transverse layers) without narrow side bonding. It can currently be produced with dimensions of up to 9' 8 1/8" x 52' 5 15/16" (2.95 × 16.0 m).

Example:
Design of a 5-layer CLT solid-wood panel

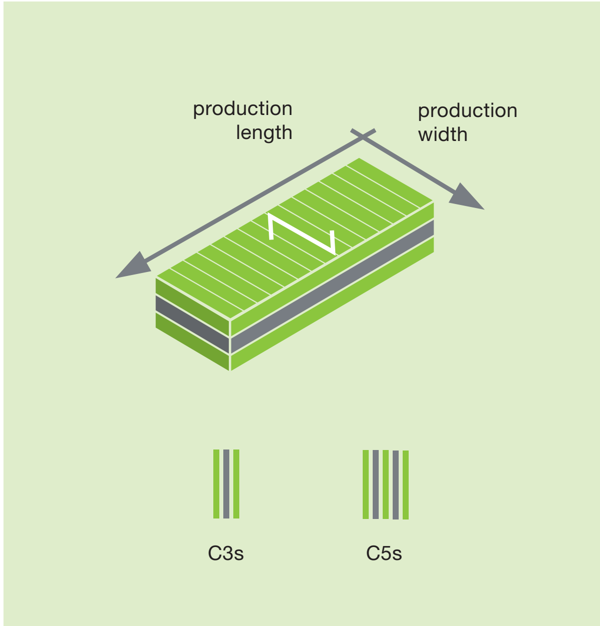


* From five layers, middle layers (transverse layers) can also be processed without narrow side bonding.

Standard designs

C panels
The grain direction of the cover layers is always parallel to the production widths.

Thickness [in]	Panel type [–]	Layers [–]	Panel design [in]						
			C*	L	C*	L	C*	L	C*
2⅜"	C3s	3	13⁄16"	13⁄16"	13⁄16"				
3⅛"	C3s	3	13⁄16"	1 9⁄16"	13⁄16"				
3 9⁄16"	C3s	3	1 3⁄16"	1 3⁄16"	1 3⁄16"				
3 15⁄16"	C3s	3	1 3⁄16"	1 9⁄16"	1 3⁄16"				
4¾"	C3s	3	1 9⁄16"	1 9⁄16"	1 9⁄16"				
3 15⁄16"	C5s	5	13⁄16"	13⁄16"	13⁄16"	13⁄16"	13⁄16"		
4¾"	C5s	5	1 3⁄16"	13⁄16"	13⁄16"	13⁄16"	1 3⁄16"		
5 33⁄64"	C5s	5	1 9⁄16"	13⁄16"	13⁄16"	13⁄16"	1 9⁄16"		
6 5⁄16"	C5s	5	1 9⁄16"	13⁄16"	1 9⁄16"	13⁄16"	1 9⁄16"		



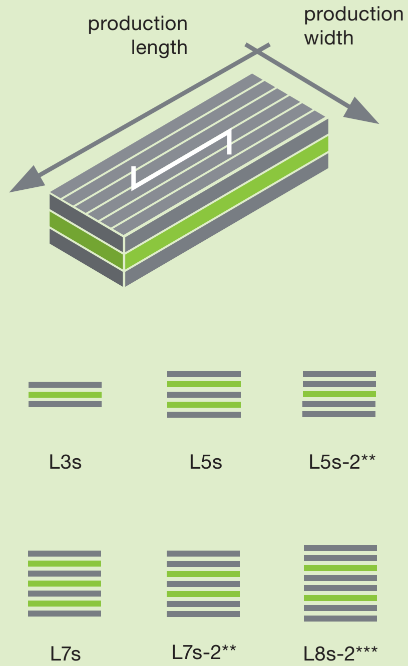
* with C panels, the sanding direction is at right angles to the grain

Production widths: 7' 4 9⁄16" (225 cm), 8' 7⁄16" (245 cm), 9' ¼" (275 cm), 9' 8⅛" (295 cm)
Production lengths: from minimum production length of 26' 2 15⁄16" (8.00 m) per charged width up to max. 52' 5 15⁄16" (16.00 m) (in 3 15⁄16" [10 cm] increments)

L panels

The grain direction of the cover layers is always at right angles to the production widths.

Thickness [in]	Panel type [–]	Layers [–]	Panel design [in]						
			L	C	L	C	L	C	L
2 3/8"	L3s	3	13/16"	13/16"	13/16"				
3 1/8"	L3s	3	13/16"	1 9/16"	13/16"				
3 9/16"	L3s	3	1 3/16"	1 3/16"	1 3/16"				
3 15/16"	L3s	3	1 3/16"	1 9/16"	1 3/16"				
4 3/4"	L3s	3	1 9/16"	1 9/16"	1 9/16"				
3 15/16"	L5s	5	13/16"	13/16"	13/16"	13/16"	13/16"		
4 3/4"	L5s	5	1 3/16"	13/16"	13/16"	13/16"	1 3/16"		
5 33/64"	L5s	5	1 9/16"	13/16"	13/16"	13/16"	1 9/16"		
6 5/16"	L5s	5	1 9/16"	13/16"	1 9/16"	13/16"	1 9/16"		
7 1/16"	L5s	5	1 9/16"	1 3/16"	1 9/16"	1 3/16"	1 9/16"		
7 7/8"	L5s	5	1 9/16"	1 9/16"	1 9/16"	1 9/16"	1 9/16"		
6 5/16"	L5s-2*	5	2 3/8"	1 9/16"	2 3/8"				
7 1/16"	L7s	7	1 3/16"	13/16"	1 3/16"	13/16"	1 3/16"	13/16"	1 3/16"
7 7/8"	L7s	7	13/16"	1 9/16"	13/16"	1 9/16"	13/16"	1 9/16"	13/16"
9 7/16"	L7s	7	1 3/16"	1 9/16"	1 3/16"	1 9/16"	1 3/16"	1 9/16"	1 3/16"
8 11/16"	L7s-2*	7	2 3/8"	1 3/16"	1 9/16"	1 3/16"	2 3/8"		
9 7/16"	L7s-2*	7	3 1/8"	13/16"	1 9/16"	13/16"	3 1/8"		
10 1/4"	L7s-2*	7	3 1/8"	1 3/16"	1 9/16"	1 3/16"	3 1/8"		
11"	L7s-2*	7	3 1/8"	1 9/16"	1 9/16"	1 9/16"	3 1/8"		
11 13/16"	L8s-2**	8	3 1/8"	1 3/16"	3 1/8"	1 3/16"	3 1/8"		
12 5/8"	L8s-2**	8	3 1/8"	1 9/16"	3 1/8"	1 9/16"	3 1/8"		

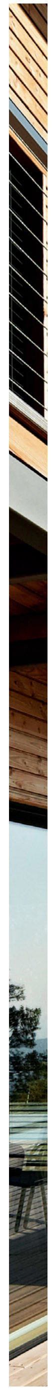


** cover layers consisting of two lengthwise layers
*** cover layers and inner layer consisting of two lengthwise layers

Surface qualities

CLT surface quality
Surface quality appearance with respect to product characteristics

Characteristics	VI	IVI	NVI
Surface finish	sanded	sanded	≤ 10 % of the surface may not be sanded
Timber species	one single species	one single species	addition of other timber species allowed
Moisture content	≤ 11 %	≤ 15 %	≤ 15 %
Narrow side bonding	occasional open joints permitted ≤ 1/16" (1 mm)	occasional open joints permitted ≤ 1/16" (2 mm)	occasional open joints permitted ≤ 1/8" (3 mm)
Discoloration	slight discoloration permitted ≤ 1 %	slight discoloration permitted ≤ 3 %	permitted
Knots — sound	permitted	permitted	permitted
Knots — black	occasional occurrences permitted ≤ 9/16" (15 mm) Ø	permitted ≤ 1 3/16" (30 mm) Ø	permitted
Loose knots, knot holes	occasional occurrences permitted ≤ 3/8" (10 mm) Ø	permitted ≤ 13/16" (20 mm) Ø	permitted
Resin pockets	occasional occurrences permitted ≤ 1/8" x 1 15/16" (5 x 50 mm)	occasional occurrences permitted ≤ 3/8" x 3 9/16" (10 x 90 mm)	permitted
Bark ingrowths	occasional occurrences permitted	occasional occurrences permitted	permitted
Rough edges / wane	not permitted	not permitted	permitted ≤ 13/16" x 19 11/16" (20 x 500 mm)
Hartwood pith	occasional occurrences permitted ≤ 15¾" (400 mm) length	permitted	permitted
Cracks and gaps between lamella (at reference moisture of 11%)	occasional occurrences permitted ≤ 1/16" (1 mm)	occasional occurrences permitted ≤ 1/16" (2 mm)	occasional occurrences permitted ≤ 1/8" (3 mm)
Boreholes from inactive insect attack	not permitted	not permitted	occasional occurrences permitted
Quality of surface finish	occasional small defects permitted	occasional defects permitted	occasional defects permitted
Quality of end grain	occasional small defects permitted	occasional defects permitted	occasional defects permitted
Manual retreatment of end grains with sand paper	yes	no	no
Surface retreatment (plugs, fillers, strips, etc.)	permitted	permitted	permitted
Chamfer on L-panels in grain direction	yes	yes	no
Sanding scratches / sanding directions	Sanding marks on L-panels run in grain direction, on C-panels across grain direction.		
CNC cutting on visual quality (VI) surface	CNC cutting on visual quality (VI) surface will be carried out exclusively with milling and cutting tools that cause no soiling through chain oil.		
Crack formations	Crack formations and open joints caused by swelling and shrinking due to later equilibrium moisture in normal use status is wood specific and cannot be prevented.		
Validity	The quality requirements to the surfaces listed above are valid: • on delivery • for top and bottom surfaces only All end grains / edges are to be considered as NVI quality.		



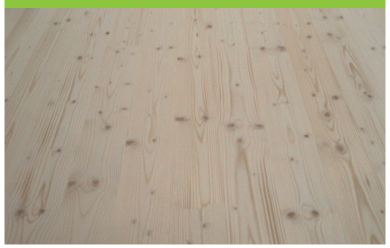
Surface quality descriptions

Stora Enso offers three different CLT surface qualities	
NVI	Non-visual quality
IVI	Industrial visual quality
VI	Visual quality

CLT qualities available from Stora Enso are based on three different surface qualities

Quality description	NVI	VI	BVI	INV	IBI	IVI
Cover layer	NVI	VI	VI	IVI	IVI	VI
Middle layer	NVI	NVI	NVI	NVI	NVI	NVI
Cover layer	NVI	NVI	VI	NVI	IVI	IVI

Spruce
VI (visual quality)



Spruce
IVI (industrial visual quality)

Spruce and pine
NVI (non-visual quality)

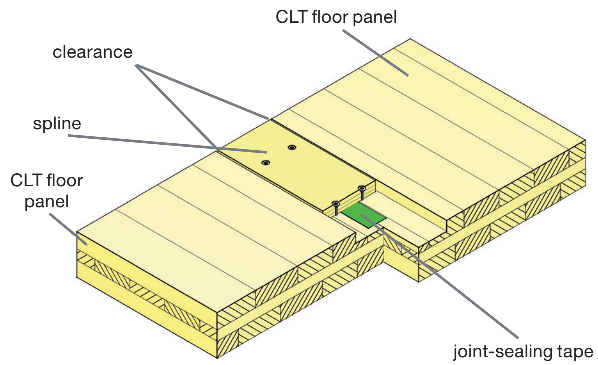
3. Structure

Examples of design details and component designs

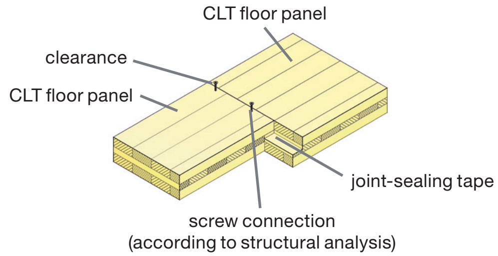
CLT elements have a wide range of applications. For example, when used on external, internal, and partition walls, due to their structure which consists of bonded boards arranged at right angles to one another, they assume both a load-bearing and a bracing function in the building.

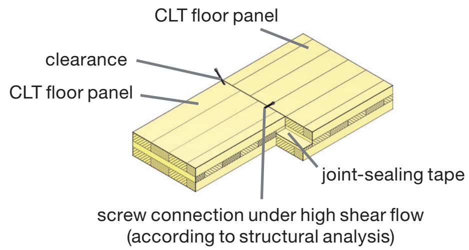
The high level of prefabrication and related short assembly times are major advantages, especially when CLT panels are used as roof elements, as buildings can be rendered rain-proof in short timeframes. Thanks to CLT, roofs and floors can be economically designed with standard span lengths, and building requirements can be fully satisfied. With the right choice of structural components this can be easily achieved and, at the same time, CLT can be combined with virtually any type of construction material.

Floor
Floor joint (butt board)

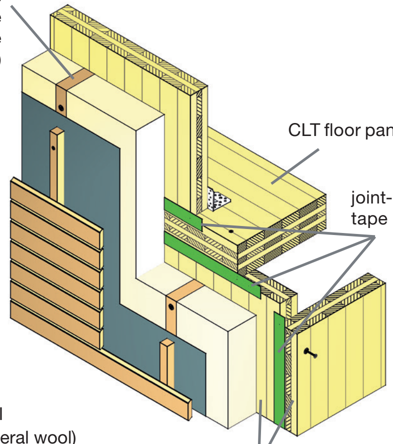


Floor
Floor joint (stepped rebate)





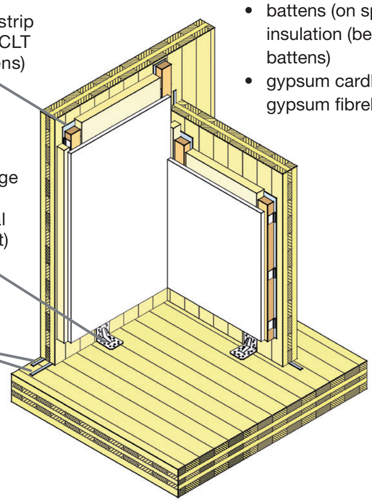
External wall
Insulation with mineral wool



Structure:
- CLT wall panel
- insulation (mineral wool)
- vertical seal (for windtightness)
- battens
- horizontal wall cladding

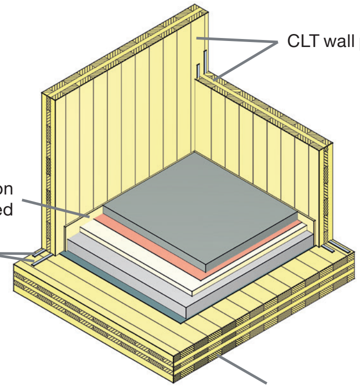
Internal wall
Facing panel (spring clips)

Structure:
- CLT wall panel
- battens (on spring clips), insulation (between battens)
- gypsum cardboard or gypsum fibreboard

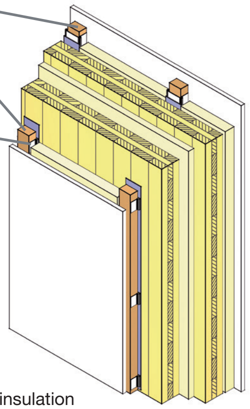


Floor structure
Wet screed

Structure:
- screed
- partition layer
- impact sound insulation
- joint filler (gravel)
- trickle protection (optional)
- CLT floor panel

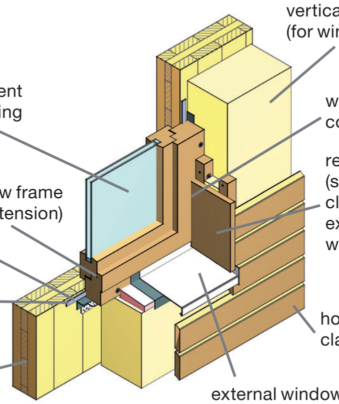


Party wall
System with double-wall CLT arrangement

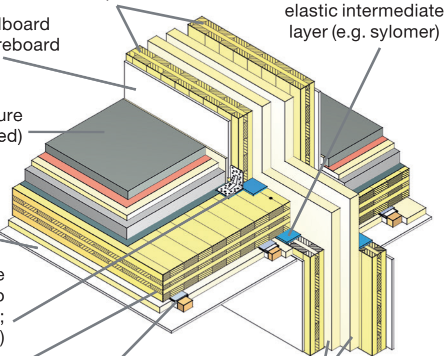


Structure:
- gypsum cardboard or gypsum fibreboard
- battens (fastened with spring clips), insulation (between battens)
- CLT wall panel
- impact sound insulation
- CLT wall panel
- battens (fastened with spring clips), insulation (between battens)
- gypsum cardboard or gypsum fibreboard

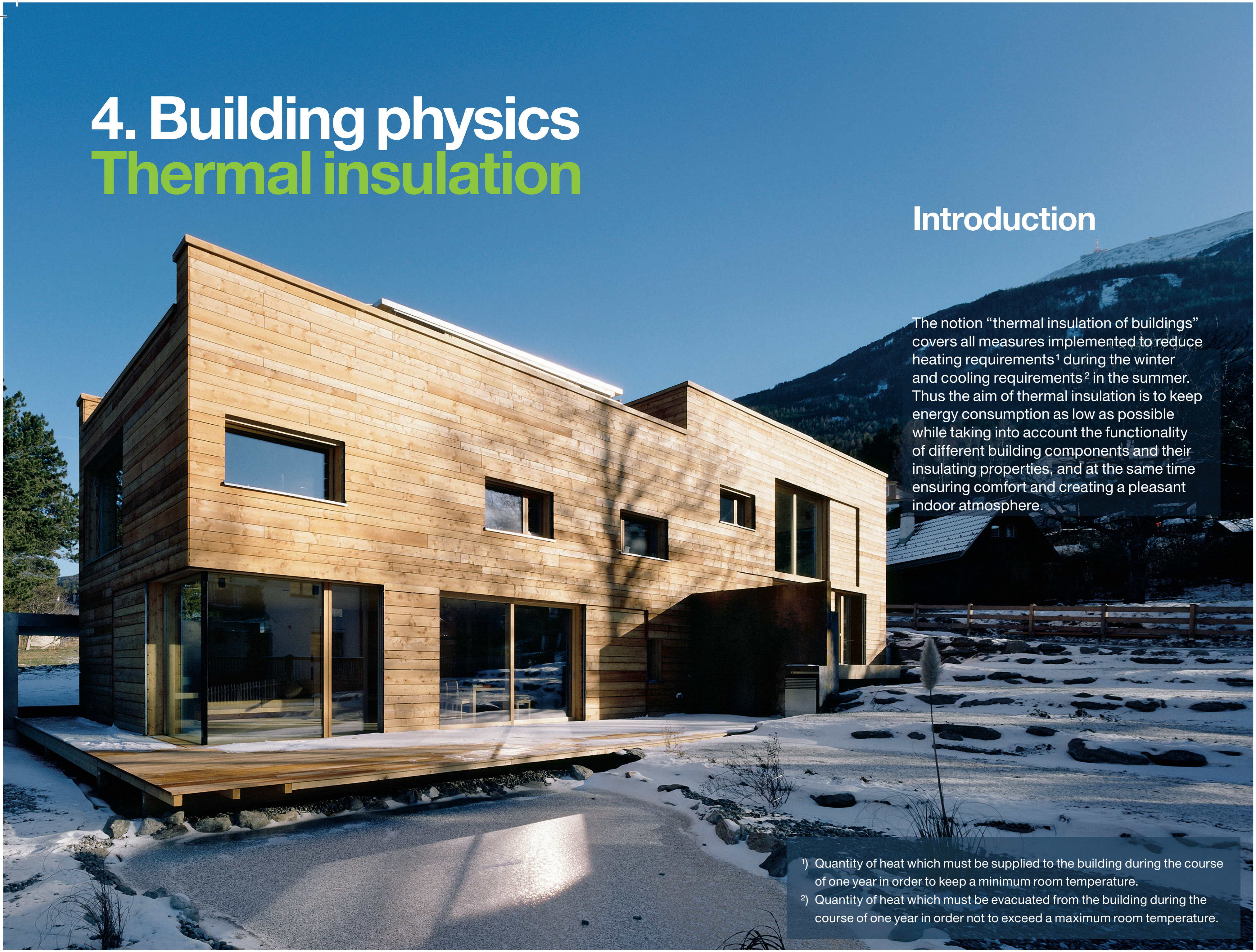
Window connection
Installation with expanding foam tape



Multi-storey residential buildings
Ground floor wall – ceiling – top floor wall



4. Building physics
Thermal insulation



Introduction

The notion “thermal insulation of buildings” covers all measures implemented to reduce heating requirements[1] during the winter and cooling requirements[2] in the summer. Thus the aim of thermal insulation is to keep energy consumption as low as possible while taking into account the functionality of different building components and their insulating properties, and at the same time ensuring comfort and creating a pleasant indoor atmosphere.

[1]) Quantity of heat which must be supplied to the building during the course of one year in order to keep a minimum room temperature.
[2]) Quantity of heat which must be evacuated from the building during the course of one year in order not to exceed a maximum room temperature.

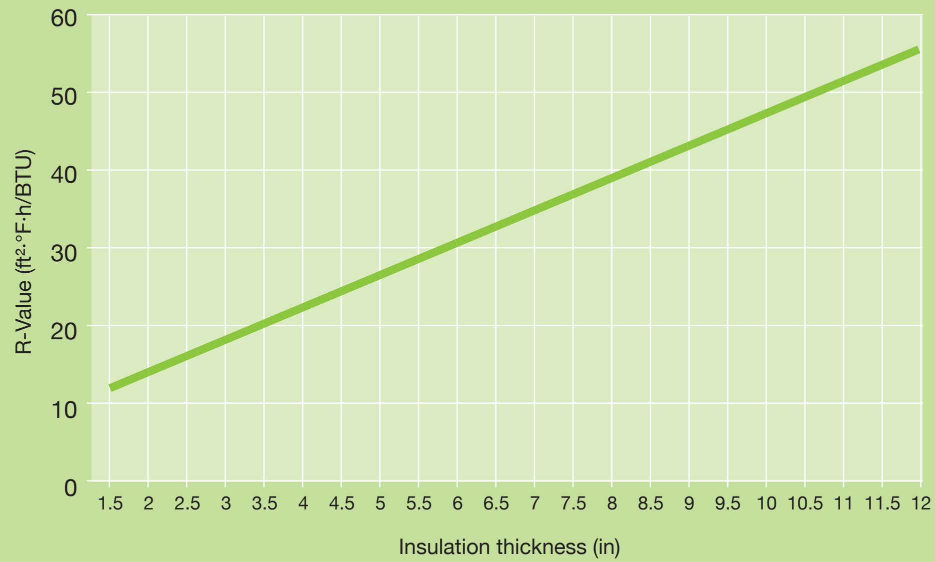
Thermal insulation with CLT

The thermal performance of a component is determined by its R-value or rate of transfer of heat (also known as thermal resistance). The location in the building and the structure, thermal conductivity and dimensions of the individual materials contained must be known in order to calculate this value. The thermal conductivity, of wood is essentially determined by its bulk density and wood moisture content and can be calculated for CLT with a value of 0.07 BTU/(ft.h.°F).

The following illustration shows a graph on which the R-values of insulated CLT panels with a thickness of 3 15⁄16" (100 mm) are plotted depending on the thickness of the insulation material thermal insulation with a thermal conductivity of 0.023 BTU/(ft.h.°F).

R-Value [°F·ft²·h/BTU]

Of a 3 15⁄16" CLT panel with a variable insulation value



Thermal insulation factors and principles in the winter

- avoidance of exposed locations
- preference given to a compact construction method
- optimum building orientation particularly in terms of the windows
- sufficiently insulated building envelope
- avoidance of thermal bridges
- sufficient airtightness of the building envelope
- energy transmission level and shading of windows
- total surface area, orientation, and angle of inclination of windows
- thermal insulating properties of opaque exterior components
- internal heat loads (people, electrical devices, etc.)
- floor plan or spatial geometry
- ventilation of living areas
- heat-storage capacity of constructive elements in living areas

Airtightness

An airtight and windtight building envelope is an essential requirement for an energy-efficient building. An airtight layer on the inside of the building prevents the penetration of damp air and subsequently the formation of condensation in components. This impacts the heat and humidity balance, and therefore the energy balance of buildings, and is critical to the quality and durability of the building's structure.

From three layers, CLT is airtight

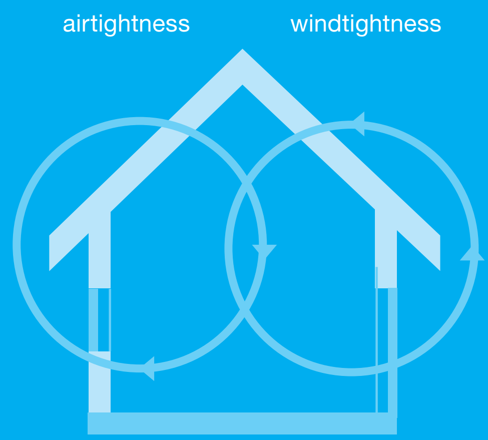
Inadequate airtightness can mean that air flows through the structure from inside to outside.

The windtightness of a building envelope is just as relevant as its airtightness. The windtight layer on the outside of the building prevents outside air from penetrating the structural components. The thermal insulation layer is therefore protected, and the components' insulating properties are not impaired. In general, windtightness is not ensured by the CLT element but rather by plaster in the case of a plastered façade or by a permeable thermo-membrane behind the ventilation level in the case of wooden façades.

Outcome:
"The element joints and the CLT element itself exhibit a high level of airtightness. The volumetric flow rates through the two joint variants and through the undisturbed surface lay outside the measurable range as a result of the high level of impermeability."

The airtightness of Stora Enso CLT has been tested by the Holzforschung Austria. This laboratory airtightness test was performed on CLT and included the element itself, a stepped rebate, and an element joint with a jointing board.

CLT is airtight



CLT also remains airtight throughout its service life

Throughout its service life, CLT is exposed to different moisture conditions. Stora Enso manufactures CLT with a relative timber moisture content of 12% ± 2% depending on the surface quality.

During the construction phase, CLT absorbs building moisture, for instance, from joint filler or cementitious material, thus increasing the timber moisture content. The service life is also characterized by seasonal fluctuations in timber moisture content. Domestic ventilation can also dry out CLT during the winter months. These moisture content fluctuations of CLT are connected to changes in the shape of the wood (swelling or shrinkage), which in extreme cases can manifest themselves through cracks in the surface (too dry) or through an undulating surface (too damp).

Tests carried out at the Technical University of Graz's laboratory for building physics demonstrated that CLT remains airtight even in the long term. The usual fluctuations in timber moisture content were simulated in the climatic cabinet, and CLT was exposed to four different moisture conditions to test its air permeability.

The test was performed on a 3-layer, 3¹⁵⁄₁₆" (100 mm)-thick CLT element in non-visual quality (CLT 100 3s NVI) with dimensions of 6' 6¾" x 6' 6¾" (2 m × 2 m), which was vertically joined once with a stepped rebate and once with a butt joint.

Soundproofing with CLT

Providing adequate protection from noise disturbance is an important factor for ensuring both building code compliance and a sense of wellbeing in buildings. Therefore, sound insulation should be a top priority during the planning stage.

Sound is defined as mechanical kinetic energy which is transmitted through elastic media by pressure and density fluctuations. Thus, sound is the audible vibration of gases, fluids, and solids. After identifying the source of noise to which a component is exposed, acoustic design distinguishes between airborne and structure-borne sound.

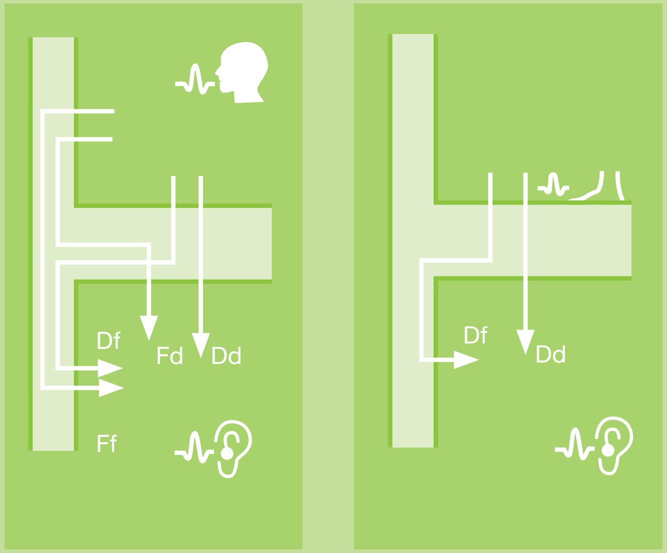
Airborne sound occurs when air sound waves cause components to vibrate, and these vibrations are transmitted to adjacent rooms in the building. Sources of airborne sound include traffic, voices, or music.

Structure-borne sound — the sound of walking, banging, scraping furniture, etc. — is transmitted to components and radiated as airborne sound into adjacent rooms. Impact sound is particularly relevant to the acoustic design.

Determining the quality of sound insulation

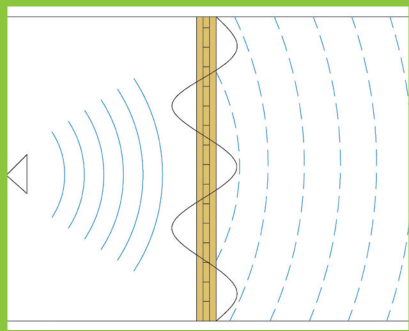
To determine the quality of sound insulation, a building component is placed in a source room (in the test facility or a building) where it is exposed to a source of noise. The incoming sound is then measured in a receiving room.

As noise levels are mostly measured in third-octave bands, measured curves are used to determine single values in order to improve the comparison of data.

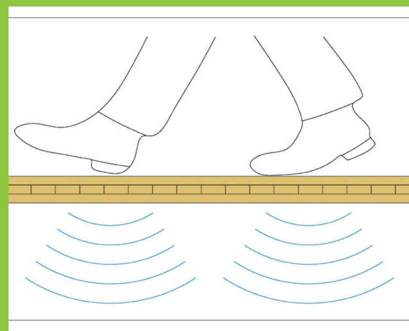


Sound transmission pathways between two rooms
F ... Flanking transmission (indirect)
D ... Direct transmission
f .... flanking radiation (indirect)
d ... direct radiation

Normative sound insulation requirements ensure that persons with normal sesitivities are provided with sufficient protection against noise from outside the building, from other parts of the same building, and from adjacent builings. The role of acoustic design is to reduce disturbing noise in the building to a defined degree.



Airborne sound



Impact sound

Explanation of acoustic terms

The STC rating, defined as “Sound Transmission Class” adopted in North America and New Zealand, is an acoustic laboratory measurement similar to R_w, however the range of assessing frequencies is shifted upwards to 125 Hz to 4000 Hz. For typical building elements the STC and R_w ratings are largely similar except where there is a significant decrease in performance at 100Hz which results in the R_w rating decreasing from the STC.

The IIC rating, defined as “Impact Insulation Class” adopted in North America and New Zealand, is an acoustic laboratory measurement that is derived from the sound pressure levels measured as described above. The IIC rating is not related to the $L_{n,w}$ rating as a higher IIC equates to a better sound insulation, however an approximate conversion is typically applied whereby the $L_{n,w}$ = 110 - IIC.

Sound insulation of CLT components

Ceiling structures

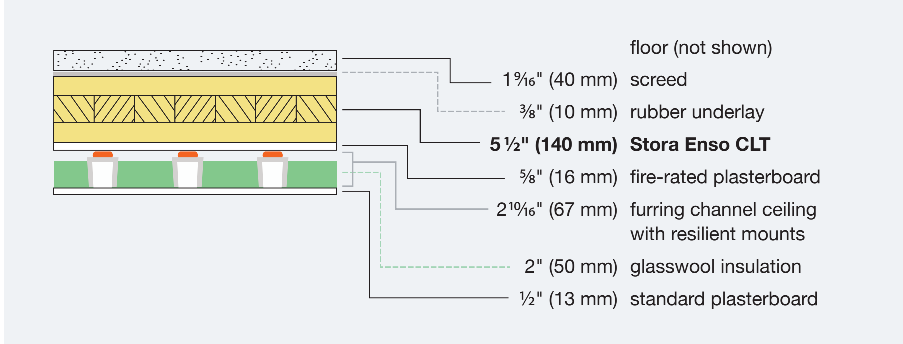
The sound insulation of ceiling structures can be improved either by increasing the mass or by improving the acoustic isolation of components. Adding mass by ballasting a raw ceiling or suspended ceiling reduces vibrations, causing less noise emissions. Above their resonance frequency, the transmission of component vibrations within the structure is reduced. Therefore, the resonance should be as low in frequency as possible (< 80 Hz).

In practice, this means installing relatively heavy screed — between 2" to 2 3/4" (5-7 cm) cement screed (note: the edge insulation strip is not cropped until the flooring has been laid) — on a soft impact sound insulation board (s' ≤ 10)[1] with backfill or bulk to provide additional mass underneath. In the case of non-suspended ceilings, the thickness of the bulk must be increased to approximately 3 15/16" (10 cm) and, due to its high sound attenuation capacity, the bulk should preferably be bonded. In terms of sound insulation, ceiling linings are most effective when decoupled (mounted on spring clips or hoops). Cavities should be insulated with mineral wool to prevent cavity resonance.

[1]) s' = dynamic stiffness (MN/m[3])

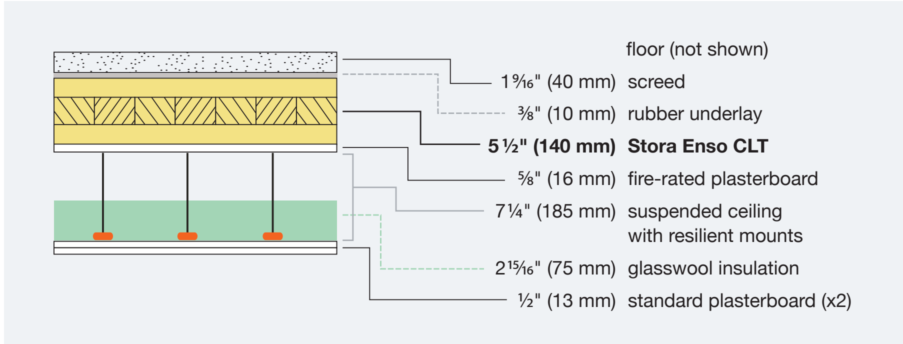
Floors

Airborne $R_w + C_{tr} \geq 50$ Impact $L_{n,w} \leq 55$ (AAAC 3 Star)



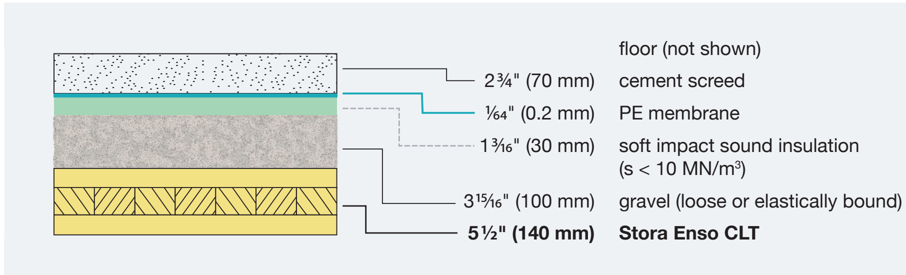
Floors

Airborne $R_w + C_{tr} \geq 50$ Impact $L_{n,w} \leq 50$ (AAAAC 4 Star)



Floors

Airborne R_w ($C;C_{tr}$) = 63 (-2;5) dB   Impact $L_{n,w}$ (C_I) = 43 (-3) dB



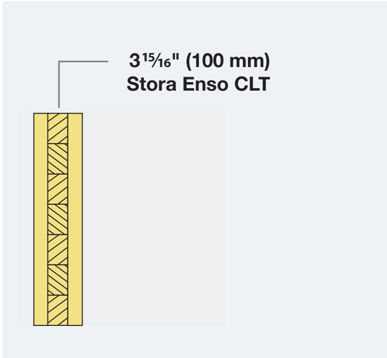
Wall panels

The sound insulation of single-layer building components is defined by their surface-based mass and flexural rigidity. According to Berger's mass law, doubling the mass increases sound insulation by 6 dB, and thereby proportionally increases the efficiency of the sound insulation. The critical coincidence frequency is the weak point of the sound insulation. For multi-layer panels with facing, greater sound insulation can be achieved with less mass.

In such mass-spring systems, below the resonance frequency f_0, the sound insulation increases at a rate of 6 dB per octave, however, above f_0, it increases by 18 dB per octave. To achieve good sound insulation, the resonance must be as low in frequency as possible (≤ 100 Hz). Resonance frequency can be reduced by increasing the gaps between layers, increasing the mass and ensuring that insulating panels are attached as flexibly as possible to the load-bearing wall. To avoid cavity resonance, the insulating panels should be filled with sound-absorbing insulation material.

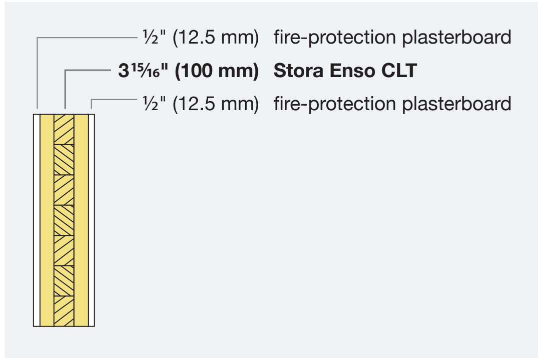
CLT non-faced wall

$R_w/C;C_{tr}$: 34 (-1;-3) db



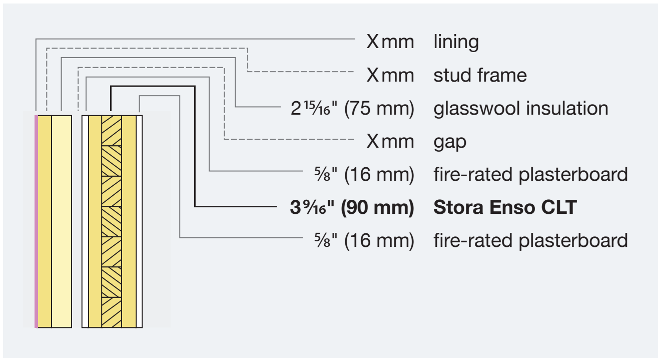
Fire protection plasterboard on both sides

$R_w/C;C_{tr}$: 37 (-1;-3) db



Walls: Discontinuous construction

$R_w + C_{tr} \geq 50$



Internal walls

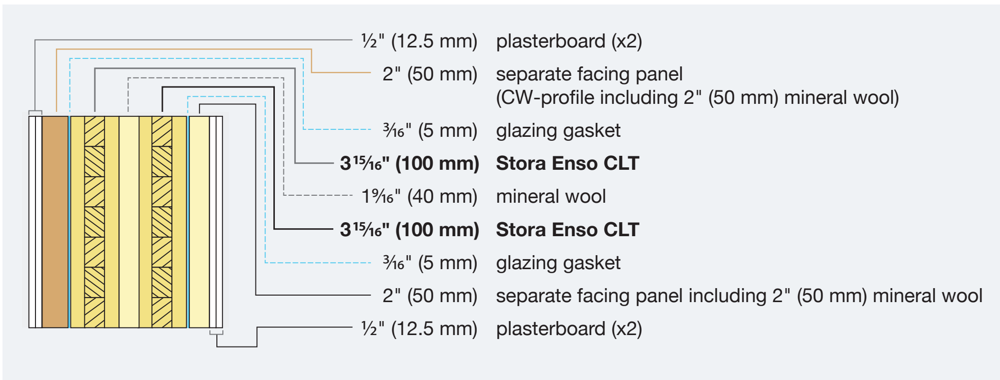
Noise levels from laboratory and construction site measurements. Details about the construction of connection nodes are available on request.

External walls

Noise levels from laboratory and construction site measurements. Details about the construction of connection nodes are available on request.

Double-layer facing panel

DnT,w (C;Ctr): 67 (–1;–4) dB



CLT and fire protection

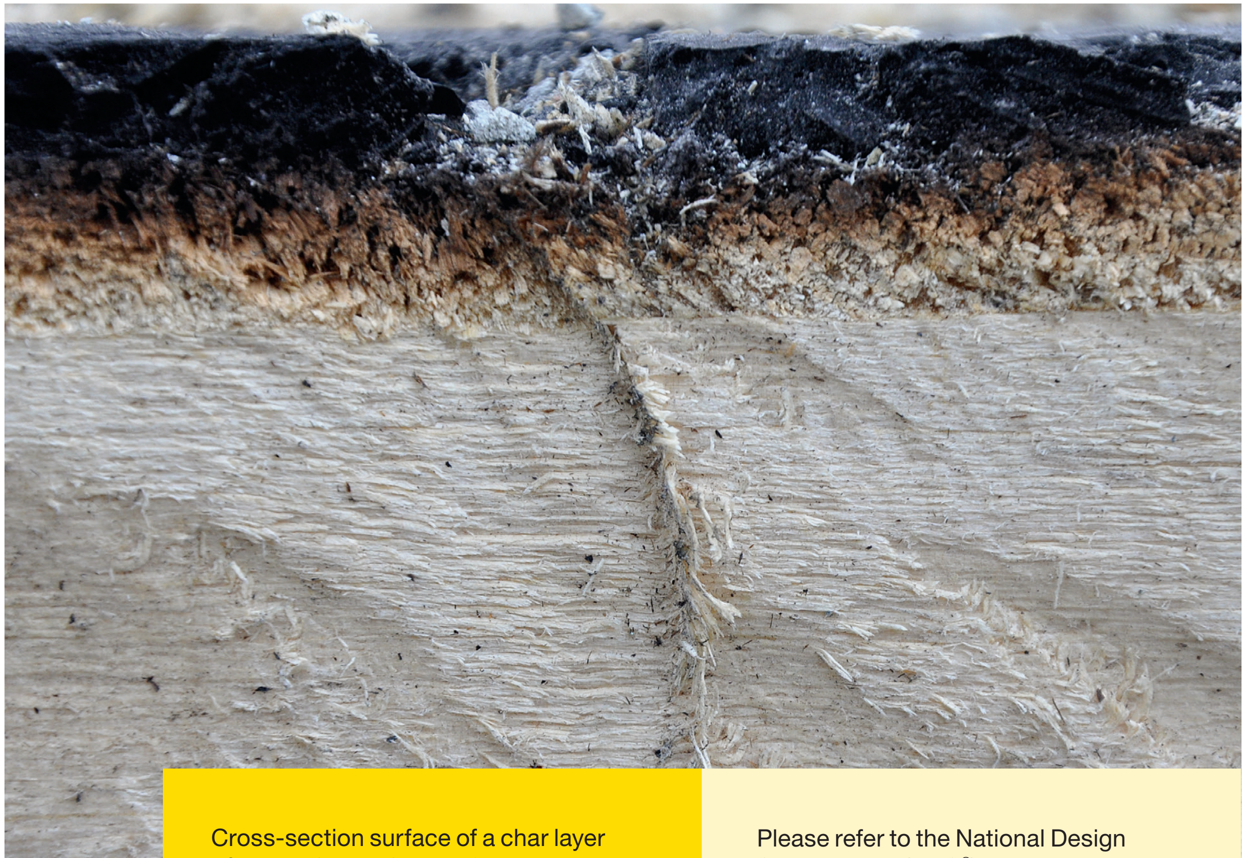
CLT exposed to fire

Stora Enso CLT has a moisture content of approx. 12%. If CLT is exposed to fire and thus to an elevated supply of energy, its temperature rises and the water molecules embedded within start to evaporate at approx. 212 °F (100 °C). At 392 °F–572 °F (200–300 °C), these chemical compounds decompose in a process known as "pyrolysis" (whereby gas emissions from combustible components in the wood burst into flame), gradually spreading along the wood, leaving a charring area behind. This char layer is formed from the carbonaceous residue of pyrolysis, which burns, generating embers. This layer's properties — in particular, low density and high permeability — act as heat insulation and protect the underlying, undamaged wood.

This produces the protective effect of the char layer on the internal CLT layers which have not yet been affected by fire, so that — unlike steel or concrete structures — although the solid wood structures become charred on the surface, the pyrolysis process and the behavior of wood when exposed to fire can actually be predicted.

Unlike steel structures, for example, which require additional fire protection measures, wood is already naturally protected by properties such as pyrolysis and the ability to form a char layer. Wood is a truly ecological building material and demonstrates unique behavior when exposed to fire, thus giving CLT building structures their excellent fire resistance.

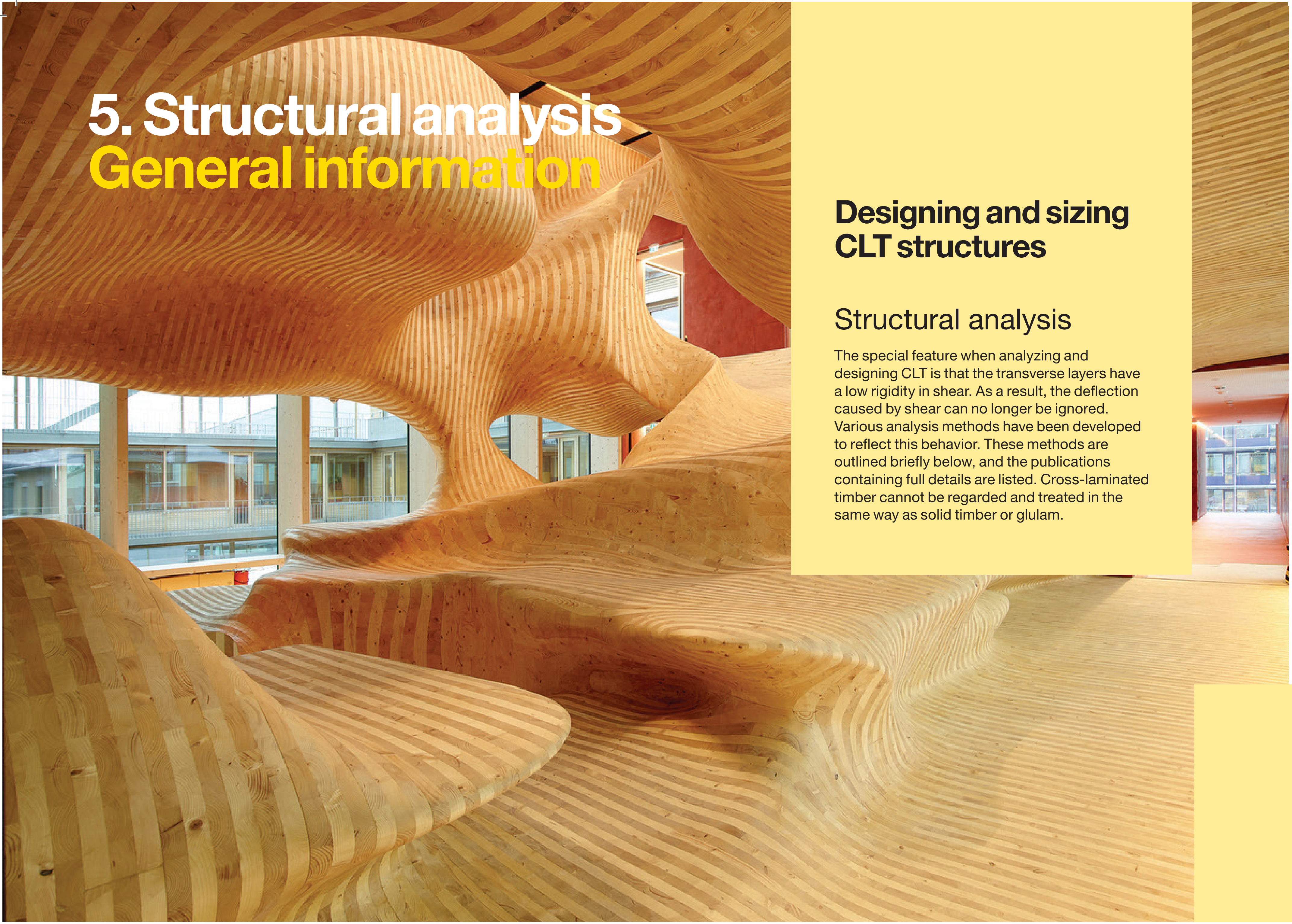
To support this statement, Stora Enso asked an accredited institute to test the fire resistance of CLT. The results speak for themselves, demonstrating the high level of fire resistance of CLT components.



Cross-section surface of a char layer of an 3⅛" (80 mm)-thick CLT element, originally clad with fire protection plasterboard, after a large-scale fire test: It is easy to identify the different layers on this cross section: the charred area (black area), followed by the pyrolysis area (brown area) — caused by the spreading fire or pyrolysis — and the undamaged wood.

Please refer to the National Design Specification (NDS®) for Wood Construction published by the American Wood Council for fire resistance information.

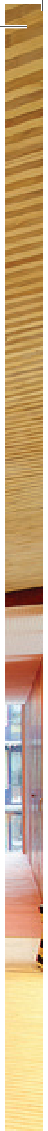
5. Structural analysis
General information



Designing and sizing CLT structures

Structural analysis

The special feature when analyzing and designing CLT is that the transverse layers have a low rigidity in shear. As a result, the deflection caused by shear can no longer be ignored. Various analysis methods have been developed to reflect this behavior. These methods are outlined briefly below, and the publications containing full details are listed. Cross-laminated timber cannot be regarded and treated in the same way as solid timber or glulam.



Analysis using laminate theory

With the aid of “panel design factors”

This analysis method does not account for deflection from shear and therefore only applies to relatively large span/thickness ratios (approx. > 30). For symmetrical panel designs, equations for calculating the effective flexural rigidity Elef in panels and discs are available directly from Stora Enso.

With the aid of the “shear correction coefficient”

Applying the appropriate corrective shear coefficient in the analysis of the shear rigidity of a CLT section, returns the shear deformation of a CLT panel (e.g.: floor or roof). This deflection needs to be added to the elastic deflection, based on the Euler Bernoulli theory. This assembly of theories is also called the Timoschenko beam theory.State of the art software for structural engineering is able to include shear deformations in the design.

Analysis using the γ-method

This method, based on the “Mechanically Jointed Beams Theory,” was developed to analyze flexibly connected beam sections and can also be applied to CLT. It is sufficiently precise for common building dimensions, simple supported CLT panels and sinusoidal load distribution and is described for use with cross-laminated timber.

This method introduced a connection efficiency factor to take the shear deformation of the perpendicular layer into account.

Analysis using the shear analogy method

The shear analogy method is known as a precise method for calculating cross-laminated timber with any type of layer structures. However, the application is not practical and requires ideally engineering software.

2D shell analysis of CLT

Analysis using beam grid models

CLT panels for floors and roofs, following a more complex shape in plan, can be modelled, using 2D frame programs or FEM software. In this case, the representative beams in X direction have a flexural rigidity of CLT along its X axis and vice versa for the Y direction.

Analysis using FEM software

Almost any CLT structure can be designed, using FEM software. If the software includes a laminate or CLT design module, the design becomes more user friendly.

Connector design in CLT

More detailed information can be found in the technical assessment documents of the respective connector manufacturer.

As the board layers are bonded at right angles to each other, the load is transferred along two main axes — also known as biaxial load bearing. In the past, this was the domain of reinforced concrete structures. CLT’s advantage in this area is a more flexible plan layout; designs can also be simplified, and lower floor to floor heights are possible. Although diagonally-projecting or point-supported structures require more planning effort, they are perfectly feasible.

CLT panels have a particularly high load bearing capacity as point loads are generally spread across the entire panel width due to the cross layers. The high rigidity of CLT is very beneficial for the bracing of a building.

Designing CLT using Stora Enso's engineering software

Stora Enso offers Calculatis, a timber design tool, free of charge at calculatis.storaenso.com. Prospective customers can use Calculatis to analyze common building components made from CLT and other timber products.

Calculatis can calculate the following CLT elements:

- floors or roofs
- rib panels
- shear walls
- deep beams
- headers above windows and doors
- 2-way cantilever panels
- supports
- load distribution on shear walls
- connectors
- timber concrete composite panels
- basics in building physics

Preliminary U.S. design tables

The following pages contain U.S. design tables intended to provide preliminary design assistance. The following tables cannot replace a full structural design. Below are three examples that illustrate how to use the following design tables.

FLOOR: 55PSF (RESIDENTIAL & CLASSROOM)—NO TOPPING

Layup	Normal conditions: Strength ft (m)	Normal conditions: D / V ft (m)	Fire conditions: 60min ft (m)	Fire conditions: 120min ft (m)
60 L3s	9.95 (3.03)	7.84 (2.39) - D	↓ 1.5 (0.46)	X
100 L3s	15.89 (4.84)	11.84 (3.61) - V	↓ 8.31 (2.53)	↓ 1.1 (0.34)
120 L3s	19.06 (5.81)	13.69 (4.17) - V	↓ 10.92 (3.33)	↓ 7.8 (2.38)
120 L5s	18.24 (5.56)	13.43 (4.09) - V	↓ 17.73 (5.40)	↓ 4.52 (1.38)
140 L5s	21.51 (6.56)	15.28 (4.66) - V	↓ 19.88 (6.06)	↓ 10.77 (3.28)
160 L5s	23.83 (7.26)	16.78 (5.11) - V	✓	↓ 10.01 (3.05)
180 L5s	25.73 (7.84)	17.97 (5.48) - V	✓	↓ 18.15 (5.53)
200 L5s	27.46 (8.37)	19.08 (5.82) - V	✓	↓ 26.36 (8.03)
220 L7s-2	31.92 (9.73)	21.36 (6.51) - V	✓	↓ 28.96 (8.83)
240 L7s-2	35.42 (10.80)	23.28 (7.10) - V	✓	↓ 33.86 (10.32)
280 L7s-2	39.49 (12.04)	25.58 (7.80) - V	✓	↓ 36.51 (11.13)

Too thin panel for that fire duration

Max span is governed by normal conditions design

Max span is reduced by Fire requirements compared to Normal conditions design

EXAMPLE 1: Intermediate residential floor / Expected floor span 14 ft / Deflection- Vibration is considered / No fire requirement
Result => STORA ENSO CLT 140 L5s

EXAMPLE 2: Same conditions as Example 1 but 1 hour Fire resistance required
Result => STORA ENSO CLT 140 L5s

EXAMPLE 3: Same conditions as Example 1 but 2 hours Fire resistance required
Result => STORA ENSO CLT 180 L5s

Design notes

1. Span tables include
   a. Floor - NO TOPPING: panel selfweight plus 15psf for miscellaneous superimposed dead load allowance.
   b. Floor - 2in CONCRETE TOPPING: panel self-weight, 25psf for concrete topping, plus 15psf for miscellaneous superimposed dead load allowance.
   c. Roof: panel self-weight plus 10psf miscellaneous superimposed dead load.
2. CLT is not an isotropic material. Presented values to be used for bending of panels in the major strength axis only.
3. Span tables are intended for preliminary design only – responsible engineer shall ensure that the panel meets all the requirements set forth in local Building Code for the project.
4. Tabulated deflection spans are based on the requirements of the IBC 2018 Table 1604.3 (L/360 for live or Snow loads; L/180 for floors in total and L/240 for roofs in total). Engineer to ensure limits are appropriate. Ceiling finishes may require tighter deflection limits.
5. Instantaneous elastic deflection due to long-term dead loads has been adjusted by a creep factor of 2.0 for dry service condition per NDS 2018 Cl. 3.5.2 for long-term loading.
6. Spans are assumed to be equal for double span panels. Where two spans are not equal, use longer span for the design tables.
7. Panels assumed to be simply supported with pin support conditions spanning from center lines of support.
8. Pattern live loads not considered.
9. Density of timber assumed to be 35pcf.
10. Floor vibration controlled span calculated per the simplified design method outlined in the CLT Handbook, US Edition, 2013.
11. Maximum spans rounded to nearest 0.1ft.
12. Initial weight of panel prior to fire considered in fire governed span design.
13. Maximum span based on Allowable Stress Design (ASD).
14. Floor - Live Load Assumptions per ASCE 7-16 Table 4.3-1.
    a. Residential & Classrooms: 40psf + 15psf Partition Load = 55psf .
    b. Offices: 50psf + 15psf Partition Load = 65psf.
    c. Assembly: 100psf (Partition Load not included per ASCE 7-16 Cl. 4.3.2).
15. Roof - All adjustment factors per NDS 2018, Table 10.3.1 set equal to 1.0. Load Duration Factor, CD = 1.15 per Cl. 2.3.2 for Snow loading.
16. Max span may be governed by maximum panel length of 52.5ft.

FLOOR: 55PSF (RESIDENTIAL & CLASSROOM)—NO TOPPING

	Normal conditions		Fire conditions	
	Strength	D / V	60min	120min
Layup	ft (m)	ft (m)	ft (m)	ft (m)
60 L3s	9.95 (3.03)	7.84 (2.39) - D	↓ 1.5 (0.46)	X
100 L3s	15.89 (4.84)	11.84 (3.61) - V	↓ 8.31 (2.53)	↓ 1.1 (0.34)
120 L3s	19.06 (5.81)	13.69 (4.17) - V	↓ 10.92 (3.33)	↓ 7.8 (2.38)
120 L5s	18.24 (5.56)	13.43 (4.09) - V	↓ 17.73 (5.40)	↓ 4.52 (1.38)
140 L5s	21.51 (6.56)	15.28 (4.66) - V	↓ 19.88 (6.06)	↓ 10.77 (3.28)
160 L5s	23.83 (7.26)	16.78 (5.11) - V	✓	↓ 10.01 (3.05)
180 L5s	25.73 (7.84)	17.97 (5.48) - V	✓	↓ 18.15 (5.53)
200 L5s	27.46 (8.37)	19.08 (5.82) - V	✓	↓ 26.36 (8.03)
220 L7s-2	31.92 (9.73)	21.36 (6.51) - V	✓	↓ 28.96 (8.83)
240 L7s-2	35.42 (10.80)	23.28 (7.10) - V	✓	↓33.86 (10.32)
280 L7s-2	39.49 (12.04)	25.58 (7.80) - V	✓	↓ 36.51 (11.13)

FLOOR: 65PSF (OFFICE)—NO TOPPING

	Normal conditions		Fire conditions	
	Strength	D / V	60min	120min
Layup	ft (m)	ft (m)	ft (m)	ft (m)
60 L3s	9.36 (2.85)	7.39 (2.25) - D	↓ 1.41 (0.43)	X
100 L3s	14.99 (4.57)	11.84 (3.61) - V	↓ 7.84 (2.39)	↓ 1.04 (0.32)
120 L3s	18.02 (5.49)	13.69 (4.17) - V	↓ 10.32 (3.15)	↓ 7.38 (2.25)
120 L5s	17.25 (5.26)	13.43 (4.09) - V	↓ 16.76 (5.11)	↓ 4.27 (1.30)
140 L5s	20.36 (6.21)	15.28 (4.66) - V	↓ 18.82 (5.74)	↓ 10.2 (3.11)
160 L5s	22.59 (6.89)	16.78 (5.11) - V	✓	↓ 9.49 (2.89)
180 L5s	24.42 (7.44)	17.97 (5.48) - V	✓	↓ 17.23 (5.25)
200 L5s	26.09 (7.95)	19.08 (5.82) - V	✓	↓ 25.05 (7.64)
220 L7s-2	30.38 (9.26)	21.36 (6.51) - V	✓	↓ 27.55 (8.40)
240 L7s-2	33.73 (10.28)	23.28 (7.10) - V	✓	↓ 32.24 (9.83)
280 L7s-2	37.69 (11.49)	25.58 (7.80) - V	✓	↓ 34.84 (10.62)

FLOOR: 55PSF (RESIDENTIAL & CLASSROOM)—2" TOPPING

	Normal conditions		Fire conditions	
	Strength	D / V	60min	120min
Layup	ft (m)	ft (m)	ft (m)	ft (m)
60 L3s	8.64 (2.63)	7.05 (2.15) - D	↓ 1.3 (0.40)	X
100 L3s	13.9 (4.24)	11.39 (3.47) - D	↓ 7.26 (2.21)	↓ 0.96 (0.29)
120 L3s	16.73 (5.10)	13.68 (4.17) - D	↓ 9.58 (2.92)	↓ 6.85 (2.09)
120 L5s	16.01 (4.88)	13.36 (4.07) - D	↓ 15.56 (4.74)	↓ 3.96 (1.21)
140 L5s	18.94 (5.77)	15.28 (4.66) - V	↓ 17.5 (5.33)	↓ 9.48 (2.89)
160 L5s	21.04 (6.41)	16.78 (5.11) - V	✓	↓ 8.84 (2.69)
180 L5s	22.78 (6.94)	17.97 (5.48) - V	✓	↓ 16.08 (4.90)
200 L5s	24.37 (7.43)	19.08 (5.82) - V	✓	↓ 23.4 (7.13)
220 L7s-2	28.42 (8.66)	21.36 (6.51) - V	✓	↓ 25.78 (7.86)
240 L7s-2	31.6 (9.63)	23.28 (7.10) - V	✓	↓ 30.21 (9.21)
280 L7s-2	35.4 (10.79)	25.58 (7.80) - V	✓	↓ 32.72 (9.97)

FLOOR: 65PSF (OFFICE)—2" TOPPING

	Normal conditions		Fire conditions	
	Strength	D / V	60min	120min
Layup	ft (m)	ft (m)	ft (m)	ft (m)
60 L3s	8.24 (2.51)	6.89 (2.10) - D	↓ 1.24 (0.38)	X
100 L3s	13.29 (4.05)	11.15 (3.40) - D	↓ 6.95 (2.12)	↓ 0.92 (0.28)
120 L3s	16.01 (4.88)	13.39 (4.08) - D	↓ 9.17 (2.80)	↓ 6.55 (2.00)
120 L5s	15.32 (4.67)	13.09 (3.99) - D	↓ 14.89 (4.54)	↓ 3.79 (1.16)
140 L5s	18.14 (5.53)	15.28 (4.66) - V	↓ 16.76 (5.11)	↓ 9.08 (2.77)
160 L5s	20.17 (6.15)	16.78 (5.11) - V	✓	↓ 8.47 (2.58)
180 L5s	21.85 (6.66)	17.97 (5.48) - V	✓	↓ 15.42 (4.70)
200 L5s	23.4 (7.13)	19.08 (5.82) - V	✓	↓ 22.47 (6.85)
220 L7s-2	27.3 (8.32)	21.36 (6.51) - V	✓	↓ 24.77 (7.55)
240 L7s-2	30.38 (9.26)	23.28 (7.10) - V	✓	↓ 29.04 (8.85)
280 L7s-2	34.08 (10.39)	25.58 (7.80) - V	✓	↓ 31.51 (9.60)

FLOOR: 100PSF (ASSEMBLY)—NO TOPPING

Layup	Normal conditions Strength ft (m)	Normal conditions D / V ft (m)	Fire conditions 60min ft (m)	Fire conditions 120min ft (m)
60 L3s	7.9 (2.41)	6.35 (1.94) - D	↓1.19 (0.36)	X
100 L3s	12.75 (3.89)	10.48 (3.19) - D	↓ 6.66 (2.03)	↓ 0.88 (0.27)
120 L3s	15.38 (4.69)	12.71 (3.87) - D	↓ 8.81 (2.69)	↓ 6.3 (1.92)
120 L5s	14.72 (4.49)	12.43 (3.79) - D	↓ 14.31 (4.36)	↓ 3.64 (1.11)
140 L5s	17.44 (5.32)	14.74 (4.49) - D	↓ 16.12 (4.91)	↓ 8.73 (2.66)
160 L5s	19.41 (5.92)	16.72 (5.10) - D	✓	↓ 8.15 (2.48)
180 L5s	21.04 (6.41)	17.97 (5.48) - V	✓	↓ 14.85 (4.53)
200 L5s	22.54 (6.87)	19.08 (5.82) - V	✓	↓ 21.65 (6.60)
220 L7s-2	26.32 (8.02)	21.36 (6.51) - V	✓	↓ 23.87 (7.28)
240 L7s-2	29.3 (8.93)	23.28 (7.10) - V	✓	↓ 28.01 (8.54)
280 L7s-2	32.91 (10.03)	25.58 (7.80) - V	✓	↓ 30.42 (9.27)

FLOOR: 100PSF (ASSEMBLY)—2" TOPPING

Layup	Normal conditions Strength ft (m)	Normal conditions D / V ft (m)	Fire conditions 60min ft (m)	Fire conditions 120min ft (m)
60 L3s	7.2 (2.19)	6.35 (1.94) - D	↓ 1.08 (0.33)	X
100 L3s	11.66 (3.55)	10.42 (3.18) - D	↓ 6.09 (1.86)	↓ 0.81 (0.25)
120 L3s	14.07 (4.29)	12.55 (3.83) - D	↓ 8.06 (2.46)	↓ 5.76 (1.76)
120 L5s	13.47 (4.11)	12.27 (3.74) - D	↓ 13.09 (3.99)	↓ 3.33 (1.01)
140 L5s	15.98 (4.87)	14.44 (4.40) - D	↓ 14.77 (4.50)	↓ 8 (2.44)
160 L5s	17.81 (5.43)	16.26 (4.96) - D	✓	↓ 7.48 (2.28)
180 L5s	19.33 (5.89)	17.77 (5.42) - D	✓	↓ 13.64 (4.16)
200 L5s	20.74 (6.32)	19.08 (5.82) - V	✓	↓ 19.92 (6.07)
220 L7s-2	24.25 (7.39)	21.36 (6.51) - V	✓	↓ 22 (6.71)
240 L7s-2	27.03 (8.24)	23.28 (7.10) - V	✓	↓ 25.84 (7.88)
280 L7s-2	30.43 (9.28)	25.58 (7.80) - V	✓	↓ 28.13 (8.57)

ROOF: 30PSF SNOW—SINGLE SPAN

Layup	Normal conditions Strength ft (m)	Normal conditions D / V ft (m)	Fire conditions 60min ft (m)	Fire conditions 120min ft (m)
60 L3s	13.66 (4.16)	8.57 (2.61)	↓ 1.92 (0.59)	X
100 L3s	21.43 (6.53)	13.49 (4.11)	↓ 10.45 (3.19)	↓ 1.39 (0.42)
120 L3s	25.51 (7.78)	16.02 (4.88)	↓ 13.64 (4.16)	↓ 9.74 (2.97)
120 L5s	24.42 (7.44)	15.63 (4.76)	↓ 22.13 (6.75)	↓ 5.64 (1.72)
140 L5s	28.58 (8.71)	18.16 (5.54)	↓ 24.64 (7.51)	↓13.35 (4.07)
160 L5s	31.45 (9.59)	20.19 (6.15)	✓	↓ 12.32 (3.76)
180 L5s	33.73 (10.28)	21.86 (6.66)	✓	↓ 22.2 (6.77)
200 L5s	35.77 (10.90)	19.34 (5.89)	✓	↓ 32.04 (9.77)
220 L7s-2	41.37 (12.61)	26.55 (8.09)	↓ 39.19 (11.95)	↓ 35 (10.67)
240 L7s-2	45.64 (13.91)	29.16 (8.89)	✓	↓ 40.69 (12.40)
280 L7s-2	50.39 (15.36)	32.42 (9.88)	✓	↓ 43.44 (13.24)

ROOF: 60PSF SNOW—SINGLE SPAN

Layup	Normal conditions Strength ft (m)	Normal conditions D / V ft (m)	Fire conditions 60min ft (m)	Fire conditions 120min ft (m)
60 L3s	10.67 (3.25)	7.49 (2.28)	↓ 1.5 (0.46)	X
100 L3s	17.04 (5.19)	11.97 (3.65)	↓ 8.31 (2.53)	↓ 1.1 (0.34)
120 L3s	20.44 (6.23)	14.3 (4.36)	↓ 10.92 (3.33)	↓ 7.8 (2.38)
120 L5s	19.57 (5.96)	13.96 (4.26)	↓ 17.73 (5.40)	↓ 4.52 (1.38)
140 L5s	23.07 (7.03)	16.32 (4.97)	↓ 19.88 (6.06)	↓ 10.78 (3.29)
160 L5s	25.56 (7.79)	18.24 (5.56)	✓	↓10.01 (3.05)
180 L5s	27.59 (8.41)	19.82 (6.04)	✓	↓ 18.16 (5.54)
200 L5s	29.44 (8.97)	21.3 (6.49)	✓	↓ 26.36 (8.03)
220 L7s-2	34.24 (10.44)	24.26 (7.39)	↓ 32.44 (9.89)	↓ 28.96 (8.83)
240 L7s-2	37.98 (11.58)	26.74 (8.15)	✓	↓ 33.86 (10.32)
280 L7s-2	42.35 (12.91)	29.89 (9.11)	✓	↓ 36.51 (11.13)

DESIGN VALUES: UNITED STATES (Canada design values available on request from Stora Enso.)

Layup #	MAJOR STRENGTH DIRECTION				MINOR STRENGTH DIRECTION				30MIN FRR		60MIN FRR		90MIN FRR		120MIN FRR	
	$EI_{eff,0}$ (10^6 lbf·in²/ft)	$GA_{eff,0}$ (10^6 lbf/ft)	$F_bS_{eff,0}$ (lbf·ft/ft)	$V_{s,0}$ (lbf/ft)	$EI_{eff,90}$ (10^6 lbf·in²/ft)	$GA_{eff,90}$ (10^6 lbf/ft)	$F_bS_{eff,90}$ (lbf·ft/ft)	$V_{s,90}$ (lbf/ft)	$M_{0, 30min}$ (lbf·ft/ft)	$V_{0, 30min}$ (lbf/ft)	$M_{0, 60min}$ (lbf·ft/ft)	$V_{0, 60min}$ (lbf/ft)	$M_{0, 90min}$ (lbf·ft/ft)	$V_{0, 90min}$ (lbf/ft)	$M_{0, 120min}$ (lbf·ft/ft)	$V_{0, 120min}$ (lbf/ft)
60 L3s	19.1	0.3	953	850	0.7	0.3	129	283	313	780	21.7	205	0	0	0	0
80 L3s	41.2	0.4	1544	1134	5.9	0.7	517	567	313	780	313	780	56.9	332	0	0
90 L3s	64.3	0.5	2144	1276	2.5	0.5	291	425	1080	2494	704	1169	225	661	0	0
100 L3s	85.9	0.5	2575	1417	5.9	0.6	517	567	1226	2883	704	1169	597	1077	12.5	156
120 L3s	153	0.6	3811	1701	5.9	0.6	517	567	4313	3663	1252	1559	1252	1559	639	1114
100 L5s	73.1	0.6	2193	1417	19.1	0.6	1121	850	2712	2339	844	1764	272	726	0	0
120 L5s	140	0.8	3493	1701	19.1	0.7	1121	850	3318	3663	3297	2688	704	1169	214	645
140 L5s	233	1.0	4986	1984	19.1	0.7	1121	850	7010	4442	4260	3118	2223	2674	1252	1559
160 L5s	335	1.3	6284	2268	41.2	0.8	1817	1134	9928	5222	7760	3898	5768	3454	1109	2439
180 L5s	451	1.3	7513	2551	85.9	1.0	3029	1417	11532	6001	9273	4287	8989	4234	3742	3274
200 L5s	585	1.3	8772	2835	153	1.3	4484	1701	13166	6781	10847	4677	10847	4677	8089	4232
160 L5s-2*	369	1.0	6921	2268	5.9	0.7	517	567	11999	5222	4153	4247	2816	2339	2816	2339
180 L7s	426	1.4	7089	2551	114	1.0	3339	1701	11052	6001	11052	5026	4864	4004	4864	3101
200 L7s	409	1.1	6140	2835	335	2.0	7393	2268	9790	5457	9790	5457	5557	5009	4381	3118
240 L7s	832	1.5	10397	3402	451	1.9	8839	2551	16607	8340	16607	6626	15682	6534	5835	5612
220 L7s-2*	892	1.6	12156	3118	85.9	1.1	3029	1417	23534	7560	12545	6585	12213	5067	10002	4739
240 L7s-2*	1226	2.2	15315	3402	41.2	0.9	1817	1134	32894	8340	24930	7572	14531	6572	13995	5457
260 L7s-2*	1526	2.0	17600	3685	85.9	1.1	3029	1417	37701	9120	28250	8352	15614	7352	15489	5846
280 L7s-2*	1862	1.9	19942	3969	153	1.4	4484	1701	42596	9899	31635	9131	17041	8131	17041	6236
300 L8s-2**	2274	2.8	22729	4252	206	1.3	5188	1984	50554	10679	39979	9911	28129	8911	28129	7406
320 L8s-2**	2682	2.7	25135	4535	330	1.5	7268	2268	55633	11458	43614	10690	31040	9690	31040	7795

Notes (USA) :
1. Tabulated values are ASD design values,determined in accordance with the NDS2018 and ANSI/APA PRG 320-2019. 2.Strength values are only applicable in Dry Service Conditions. All adjustmentfactors per NDS Table 10. 3.1 assumed to equal 1.0 3.The tabulated values are based on a 1ftwide section of panel. 4.The transverse modulus of elasticity, EP,is estimated as E/30. 5.The shear modulus, G, is estimated asE/16. 6.The rolling shear modulus, GP, isestimated as G/10. 7.Fire resistance design values applicablefor major span direction only.

6. Project management

Project phases

1. Request for offer

In order to provide you with a timely offer for your project, please provide the following information to your local Stora Enso sales contact:

- Company name
- Brief project description including building type
- Project schedule and location
- 3D file extract with timber elements (IFC format preferred)
  - If no 3D file is available, please provide 2D drawings in DWG or DXF file format. Please note that submitting 2D drawings requires our team to prepare a 3D model which takes more time for us to process.

For more accurate price estimates, please include additional available information, such as:

- Element file
- Panel connection details
- Possible CNC processing (penetrations, connection details, etc.) not shown in the 3D model or in drawings

Charged dimensions

The “charged dimension” is the size of the raw panel that goes into our press and from which final panels are cut and processed. To maximize efficiency, we can cut multiple small panels from one large panel, a concept called “nesting.” Please note that shipping constraints may alter optimum panel dimensions, thus shipping method should be considered during the panel design process.

Example: 52' 2" (15,900 mm) × 9' 8⅛" (2,950 mm)

Charged dimensions: 9' 8⅛" (2.95) × 52' 2" (15.90)	504.9 ft² (46.91 m²)
Area of panel (net):	415.4 ft² (38.58 m²)
Cutting waste:	89.6 ft² (8.32 m²)
Charged dimensions:	504.9 ft² (46.91 m²)

Charged lengths	26' 2 15/16" (8.00 m) to 52' 5 15/16" (16.00 m) (in 3 15/16" [10 cm] increments)
Charged widths	8' 7/16" (2.45 m), 9' 1/4" (2.75 m), 9' 8⅛" (2.95 m)

- Additional products required (e.g., fixings, membranes, sealant, etc.)
- Lifting devices
- Chain-of-custody/sustainability certification requirements (e.g., FSC, PEFC, etc.)
- Desired shipping method
- Delivery location for materials (if different from project site)
- Installation plan

2. Project offer

Depending on the size and complexity of your project, as well as the quality of information you provide in your request, Stora Enso typically requires one to two weeks to prepare an offer for your project.

Once your offer is ready, your Stora Enso sales contact will provide you with the following:

- Offer document with price estimates
- Offer summary presentation
- Offer terms and conditions

If requested, you will also receive the following:

- Solutions for further wood processing
- Delivery options and lead times
- Pre-dimensioning
- Element nesting configurations for optimal panel manufacturing

3. Review & accept

We make every effort in our offers to accurately reflect your project's assumptions and requirements. It is important that you review in detail the offer we provide, with specific attention to the following:

- Unit rates
- Delivery/shipping method & delivery location
- Terms and conditions

If required, your Stora Enso sales contact will work with you to adjust our offer should project assumptions or requirements change prior to offer acceptance. The offer validity period varies depending on market, project size, and agreements with the customer.

If the final offer meets with your approval and you wish to move forward, you will sign the offer and return it to your Stora Enso sales contact.

4. Placing a reservation

After you have accepted Stora Enso's offer, you will be ready to place a production reservation. Placing a reservation means that Stora Enso logs your order officially into the production plan and reserves a slot to produce your order according to your needed delivery date.

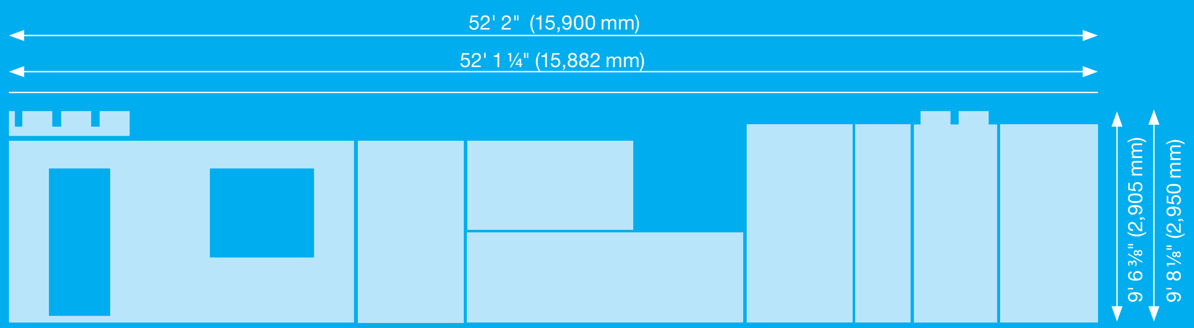
Prior to placing a reservation, you will receive our reservation checklist. After completing the checklist and highlighting if you require any additional materials (such as glulam), please send the completed checklist to your Stora Enso sales contact. It is important you provide the required order data within the agreed timeframe to make sure we can hold your reservation.

Required information sent via email for placing the reservation:

- CLT reservation checklist
- Delivery date/period/type/location
- CLT volumes
- Panel type (number of layers & thickness)
- Surface quality (VI / IVI / NVI)
- Additional painting/treatment, fixings, or other material needed

Optional information:

- Final drawings in CAD format



Nesting several final panels within charged dimensions

5. Final Drawings

Once you place your production reservation, Stora Enso will send you an order checklist to ensure we have everything needed to produce your order.

For shipments to North America, we must receive your definitive planning documents six weeks prior to your shipment date. For more information regarding the details and document requirements, please contact your Stora Enso sales contact.

Final required documents

- Filled order checklist
- Final drawings in CAD format (preferably IFC / DWG)
- Stora Enso element name/label (added as a standard by our production software)
- Element types including layer build up and surface quality
- Grain direction of the outer lamellas on all elements
- Surface quality

6. Technical elaboration & acceptance

Once we have received your final building model / drawings, we will start to produce the needed files for production. This means we translate your building drawings into the production files so that our CNC machines can produce your order.

After receiving the technical elaboration files, it's important that you review the files to reduce mistakes and revisions that can be costly and cause delays. The Stora Enso team will need written confirmation that the technical elaboration documents are correct and that the order can proceed. We cannot accept changes to your order within 12 working days of your shipment date.

If we have agreed to provide additional technical services, you will also receive those at this stage.

We will also ask you to review the following:

- nesting overview— invoiced quantity (waste management)
- control model (all the processing, surface quality, grain direction, lifting points, etc.)
- EVV (load planning and sequencing, delivery dates, transport mode, weight and size restrictions at delivery site, etc.)

7. Sales contract & acceptance

Following a thorough review of all files, we will be ready to produce your order, and the Stora Enso team will send you the sales contract. This may or may not vary from the original offer due to changes in the drawings made along the way.

Accepting the sales contract

After reviewing the sales contract sent by the Stora Enso team, you can accept the offer by signing the contract and sending it back to Stora Enso. After we receive your final confirmation, we can produce your order.

Sales contract includes the following:

- final product quantity
- final cost
- delivery information

8. Production & delivery

After receiving your final confirmation, Stora Enso can begin production of your order. Once your order has been produced it will be carefully packed and transported to the delivery site at the agreed time. When your order leaves for delivery, your invoice will also be sent.

Please contact your Stora Enso team regarding any further questions.

Shipping

Overseas transport

CLT products can be shipped to North America from our factories in Europe in 40ft High Cube containers or by MAFI trailers. As a general rule, a standard CLT shipping quantity by 40ft High Cube container is approximately 1,377 ft³ (39 m³). Please refer to the table on the right for load information relative to 40ft High Cube containers and MAFI trailers.

Overland transport

In the United States, a standard flatbed semitrailer can be loaded up to a maximum of 45,000 lbs with a maximum load length of 48 ft (14.6 m) and a maximum load width of 8.3 ft (2.5m). A density of 30.5 lb/ft³ (490 kg/m³) can be applied to calculate the load weight. As a general rule, a standard CLT shipping quantity by flatbed semitrailer is approximately 1,766 ft³ (50 m³). The maximum authorized loading height is 13 ft (4 m) for a standard semitrailer. If any special equipment is required, Stora Enso will work to provide you with project-specific needs. Please note that special equipment is provided with an additional charge.

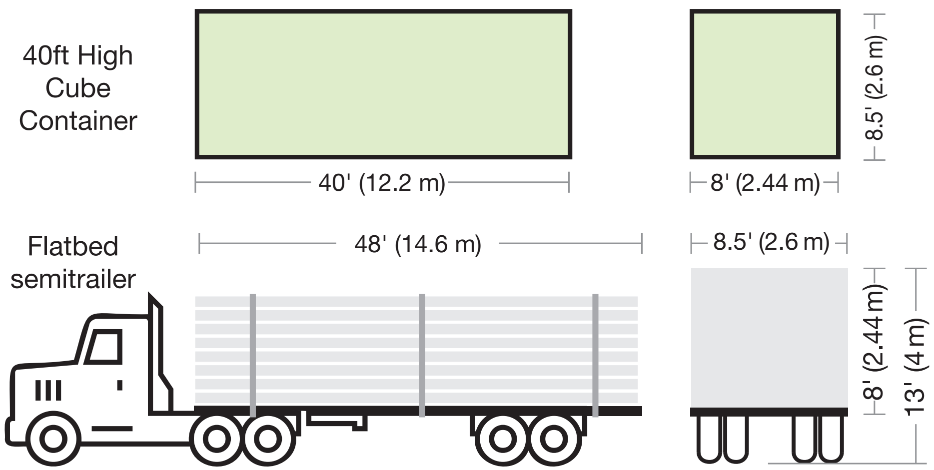
CLT panels are wrapped for shipping in a durable plastic wrap and covered with a truck tarpaulin. This is necessary to protect the panels against any ambient influences. We then place the panels between lashing straps and cardboard edge protectors to further protect them.

We use a minimum of 8 wooden skids (4" x 4" (105 × 105 mm)) as standard under the first layer of panels loaded onto the trailer. The wooden skids are equipped with non-slip pads. After that, however, every subsequent layer is stacked horizontally directly on top of the previous one.

Please inform us when placing your order (and include diagrams) if you require intermediate wooden skids for unloading by crane or forklift.

Overseas Equipment	Max. load	Max. load length	Max. load width
40ft High Cube Container	56,000 lbs	39.5' (12.03 m)	7.8' (2.35 m)
MAFI trailer	179,000 lbs	60' (18.29 m)	8.2' (2.49 m)

Overland Equipment	Max. load	Max. load length	Max. load width
Flatbed semitrailer	45,000 lbs	48' (14.6 m)	8.3' (2.5 m)



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