CLT
Symposium
February 8-9, 2011

Cross-Laminated Timber
in British Columbia

Robert Malczyk, Principal
MASc, PEng, StructEng, MIStructE, MBA

EQUILIBRIUM CONSULTING INC.
CONSULTING STRUCTURAL ENGINEERS

Outline

- Practical Design & Rules of Thumb
- Codes, Guidelines & Specs
- BC Projects
- Wider Approach

Practical Design & Rules of Thumb

- Feel: more like concrete that wood
- Span to depth ratios:
  - Floor 20-30
  - Roof 30-40
- Deflection & Vibration not Strength
- Creep – Rolling Shear

Stiffness increases for longer spans

- I effective depends on the span because X-layers alter stiffness
- 100mm CLT I effective / I full:
  - 3m span = 85%
  - 4m span = 90%
- 170mm CLT
  - 3m span = 70%
  - 4m span = 75%
  - 6m span = 80%

Deflection, Vibration & Creep

- Deflection Limits:
  - L/300 European Codes – different
  - L/400 Manufacturers Brochures
  - >6mm special calculation

- Forintek Vibration Check
  - 1 kN deflection
  - Natural Frequency - ratio

- Creep Deformation: reduce shear stiffness by 50%
  - Live Loads – in Europe partial
  - Snow Load – long term

CLT Cross-Laminated Timber

roof panel load table

CLT Roof Panel Load Table

MAX. SPAN (mm)		ROOF SNOW LOAD (kPa, unfactored)					
		1.1	1.6	2.2	2.9	3.3	8.5
	PANEL TYPE	PENTICTON	VANCOUVER	NANAIMO	PRINCE GEORGE	SQUAMISH	WHISTLER
single span	CLT-3ply-99	4450	4120	3820	3550	3420	2510
	CLT-5ply-169	6800	6360	5950	5570	5390	4050
	CLT-7ply-239	8920	8420	7920	7450	7220	5520
	CLT-9ply-309	10900	10330	9770	9230	8970	6940
double span	CLT-3ply-99	5400	4950	4550	4200	4050	2900
	CLT-5ply-169	8250	7650	7100	6600	6350	4650
	CLT-7ply-239	10900	10150	9450	8850	8550	6350
	CLT-9ply-309	13300	12500	11700	11000	10600	8000
triple span	CLT-3ply-99	5160	4750	4400	4050	3900	2850
	CLT-5ply-169	7900	7300	6800	6350	6100	4550
	CLT-7ply-239	10350	9700	9100	8500	8200	6150
	CLT-9ply-309	12650	11850	11200	10550	10200	7750

Notes:

1. Material is S-P-F No.1/No.2 for all laminations.
2. Outer laminations are 32mm thick; inner laminations are 35mm thick.
3. Specified modulus of elasticity and strength in major strength direction:
   E_0 = 9500 MPa; $f_{b,0}$ = 11.8 MPa; $f_{v,0}$ = 1.5 MPa; $f_{vr,0}$ = 0.5 MPa; $f_{c,0}$ = 11.5 MPa; $f_{t,0}$ = 5.5 MPa (ref: Table 5.3.1A of CSA-O86-09).
4. Specified modulus of elasticity and strength in minor strength direction:
   E_{90} = 9500 MPa; $f_{b,90}$ = 11.8 MPa; $f_{v,90}$ = 1.5 MPa; $f_{vr,90}$ = 0.5 MPa; (ref: Table A3 ANSI/APA PRG 320 - 75% Draft January 2011).
5. Dead load includes panel self-weight plus 0.5 kPa roofing load.
6. Maximum span is governed by dead plus snow load deflection limit of L/300.
7. All spans are assumed to be equal for multi-span panels.
8. Spans shown represent distance between the centerlines of supports.
9. Maximum spans shown are only to be used for preliminary design.
10. Engineer to ensure that L/300 deflection limit is appropriate for intended use.
11. The following factors were used for calculations: K_D = 1.0; K_s = 1.0; K_T = 1.0; K_H = 1.0.
12. Shear stiffness has been reduced by 50% to account for creep deformation.
13. Snow load is based on BCBC 2006 with the following factors:
    I_s = 1.0 for ULS; I_s = 0.9 for SLS; C_w = 1.0; C_s = 1.0; C_a = 1.0

CLT Cross-Laminated Timber

floor panel load table

CLT Floor Panel Load Table

MAX. SPAN (mm)		FLOOR LIVE LOAD (kPa, unfactored)				
		1.9	2.4	3.6	4.8	7.2
	PANEL TYPE	RESIDENTIAL	OFFICE/CLASSROOM	MECHANICAL ROOM	ASSEMBLY	LIBRARY
single span	CLT-3ply-99	**3490**	**3490**	3220	2980	2650
	CLT-5ply-169	**4920**	**4920**	**4920**	4730	4220
	CLT-7ply-239	**6200**	**6200**	**6200**	**6200**	5720
	CLT-9ply-309	**7370**	**7370**	**7370**	**7370**	7180
double span	CLT-3ply-99	**3700**	**3700**	3650	3350	2920
	CLT-5ply-169	**5150**	**5150**	**5150**	**5150**	4650
	CLT-7ply-239	**6500**	**6500**	**6500**	**6500**	6350
	CLT-9ply-309	**7800**	**7800**	**7800**	**7800**	**7800**
triple span	CLT-3ply-99	**3725**	**3725**	3500	3220	2850
	CLT-5ply-169	**5250**	**5250**	**5250**	5100	4500
	CLT-7ply-239	**6550**	**6550**	**6550**	**6550**	6150
	CLT-9ply-309	**7825**	**7825**	**7825**	**7825**	7750

Notes:

1. Material is S-P-F No.1/No.2 for all laminations.
2. Outer laminations are 32mm thick; inner laminations are 35mm thick.
3. Specified modulus of elasticity and strength in major strength direction:
   E_0 = 9500 MPa; $f_{b,0}$ = 11.8 MPa; $f_{v,0}$ = 1.5 MPa; $f_{vr,0}$ = 0.5 MPa; $f_{c,0}$ = 11.5 MPa; $f_{t,0}$ = 5.5 MPa (ref: Table 5.3.1A of CSA-O86-09).
4. Specified modulus of elasticity and strength in minor strength direction:
   E_{90} = 9500 MPa; $f_{b,90}$ = 11.8 MPa; $f_{v,90}$ = 1.5 MPa; $f_{vr,90}$ = 0.5 MPa; (ref: Table A3 ANSI/APA PRG 320 -75% Draft January 2011).
5. Dead load includes panel self-weight plus 1.0 kPa flooring load.
6. **Bold** text indicates span governed by vibration; regular text indicates span governed by dead plus live load deflection limit of L/300.
7. All spans are assumed to be equal for multi-span panels.
8. Spans shown represent distance between the centerlines of supports.
9. Maximum spans shown are only to be used for preliminary design.
10. Engineer to ensure that L/300 deflection limit is appropriate for intended use.
11. The following factors were used for calculations: K_D = 1.0; K_s = 1.0; K_T = 1.0; K_H = 1.0.

CLT Cross-Laminated Timber

floor panel with concrete topping load table

CLT Floor Panel Load Table with 2" (50mm) Concrete Topping

MAX. SPAN (mm)		FLOOR LIVE LOAD (kPa, unfactored)				
		1.9	2.4	3.6	4.8	7.2
	PANEL TYPE	RESIDENTIAL	OFFICE/CLASSROOM	MECHANICAL ROOM	ASSEMBLY	LIBRARY
single span	CLT-3ply-99	3350	3230	2990	2800	2520
	CLT-5ply-169	**4920**	**4920**	4730	4450	4030
	CLT-7ply-239	**6200**	**6200**	**6200**	6020	5480
	CLT-9ply-309	**7370**	**7370**	**7370**	**7370**	6890
double span	CLT-3ply-99	**3700**	**3700**	3420	3180	2820
	CLT-5ply-169	**5150**	**5150**	**5150**	5050	4500
	CLT-7ply-239	**6500**	**6500**	**6500**	**6500**	6150
	CLT-9ply-309	**7800**	**7800**	**7800**	**7800**	7700
triple span	CLT-3ply-99	**3725**	3600	3300	3070	2740
	CLT-5ply-169	**5250**	**5250**	5200	4860	4360
	CLT-7ply-239	**6550**	**6550**	**6550**	**6550**	5940
	CLT-9ply-309	**7825**	**7825**	**7825**	**7825**	7450

Notes:

1. Material is S-P-F No.1/No.2 for all laminations.
2. Outer laminations are 32mm thick; inner laminations are 35mm thick.
3. Specified modulus of elasticity and strength in major strength direction:
   E_0 = 9500 MPa; $f_{b,0}$ = 11.8 MPa; $f_{v,0}$ = 1.5 MPa; $f_{vr,0}$ = 0.5 MPa; $f_{c,0}$ = 11.5 MPa; $f_{t,0}$ = 5.5 MPa (ref: Table 5.3.1A of CSA-O86-09).
4. Specified modulus of elasticity and strength in minor strength direction:
   E_{90} = 9500 MPa; $f_{b,90}$ = 11.8 MPa; $f_{v,90}$ = 1.5 MPa; $f_{vr,90}$ = 0.5 MPa; (ref: Table A3 ANSI/APA PRG 320 - 75% Draft January 2011).
5. Dead load includes panel self-weight plus 1.0 kPa flooring load, and weight of 2" (50mm) normal weight concrete topping.
6. **Bold** text indicates span governed by vibration; regular text indicates span governed by dead plus live load deflection limit of L/300.
7. All spans are assumed to be equal for multi-span panels.
8. Spans shown represent distance between the centerlines of supports.
9. Maximum spans shown are only to be used for preliminary design.
10. Engineer to ensure that L/300 deflection limit is appropriate for intended use.
11. The following factors were used for calculations: K_D = 1.0; K_s = 1.0; K_T = 1.0; K_H = 1.0.

CLT concrete comparison

FLOOR SLAB COMPARISON CLT VS CONCRETE

MAX SPANS (m)	VIBRATION CONTROLLED SPAN (m)	CONCRETE SLAB-A ONE END CONT dx24 (m)	CONCRETE SLAB BOTH ENDS CONT dx28 (m)	A-SLAB THICKNESS REQUIRED (mm)	RATIO CLT/CONC THICKENESS (%)
SLT 99	**3.5**	2.4	2.8	150	**66**
SLT169	**4.9**	4.1	4.8	200	**85**
SLT 239	**6.2**	5.8	6.7	260	**92**
SLT 309	7.4	7.4	8.7	310	100

TEXT IN RED INDICATES CLT THICKNESS ADVANTAGE

Codes, Guidelines & Specs

Reference Material
Cross-Laminated Timber

Codes & Guidelines

- APA Standard for Performance Rated CLT – 75%
- FPInnovations CLT Plant Qualification Standard

Structural Notes

Cross-Laminated Timber

Structural Notes

Cross-Laminated Timber

All work to APA Standard for Performance Rated CLT ANSI/APA PRG 320-2011 and Cross-Laminated Timber Plant Qualification Standard by FPInnovations.

CLT panels consist of crosswise stacked and glued together layers of spruce planks. Bonding to be carried out exclusively with approved adhesives. Planks to be stress and quality graded and machine dried.

The lamination thickness varies between 19mm (3/4”) and 38m (1/1/2”), depending on structural requirements as shown on structural drawings unless otherwise noted

CLT panels shall have a moisture content of 12% (±2%)

Structural Notes

Cross-Laminated Timber

The Specialty Structural Engineer shall be responsible for the structural design, preparation of shop drawings and field review of all CLT components and their connections, including CLT to CLT members, CLT to glulam, CLT to steel and CLT to concrete connections. When satisfied at the end of field review, the Specialty Engineer shall provide a sealed letter to the EOR ensuring that constructed work conforms to shop drawings, as well as provide sealed sketches for all field modifications made to designs.

Sizes on structural drawings can be revised by the CLT supplier if the Specialty Engineer designs the variance to meet all structural, fire and demonstration requirements to the satisfaction of the structural engineer and architect.

CLT Projects in BC

Austria House

Whistler

Austria House

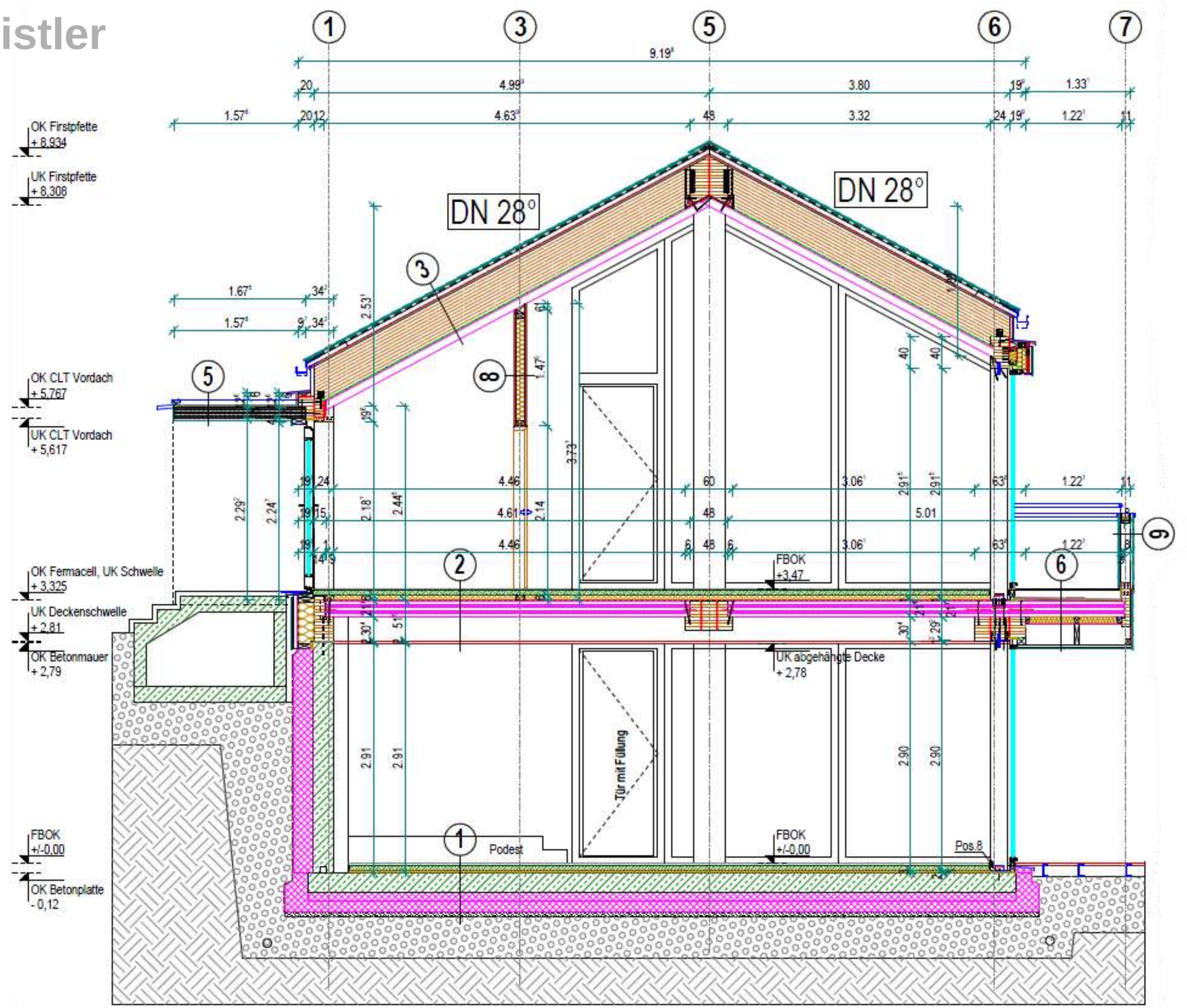
Whistler

1st in Canada to use CLT and dowelled solid wood panel construction

1st Canadian Passivhaus

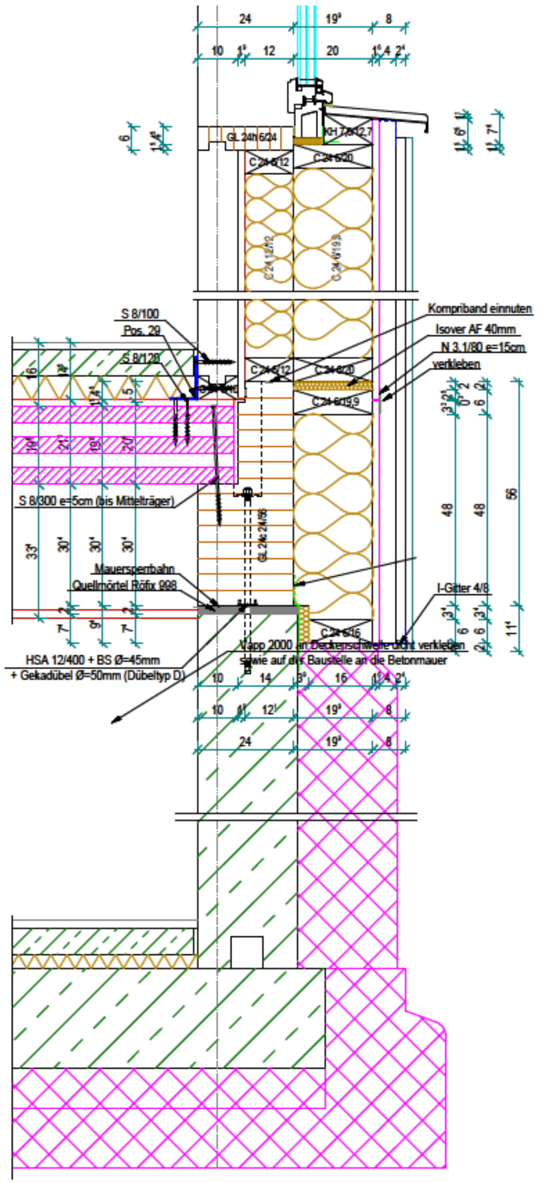
Austria House

Whistler



Austria House

Whistler



Austria House

Whistler

Austria House connections

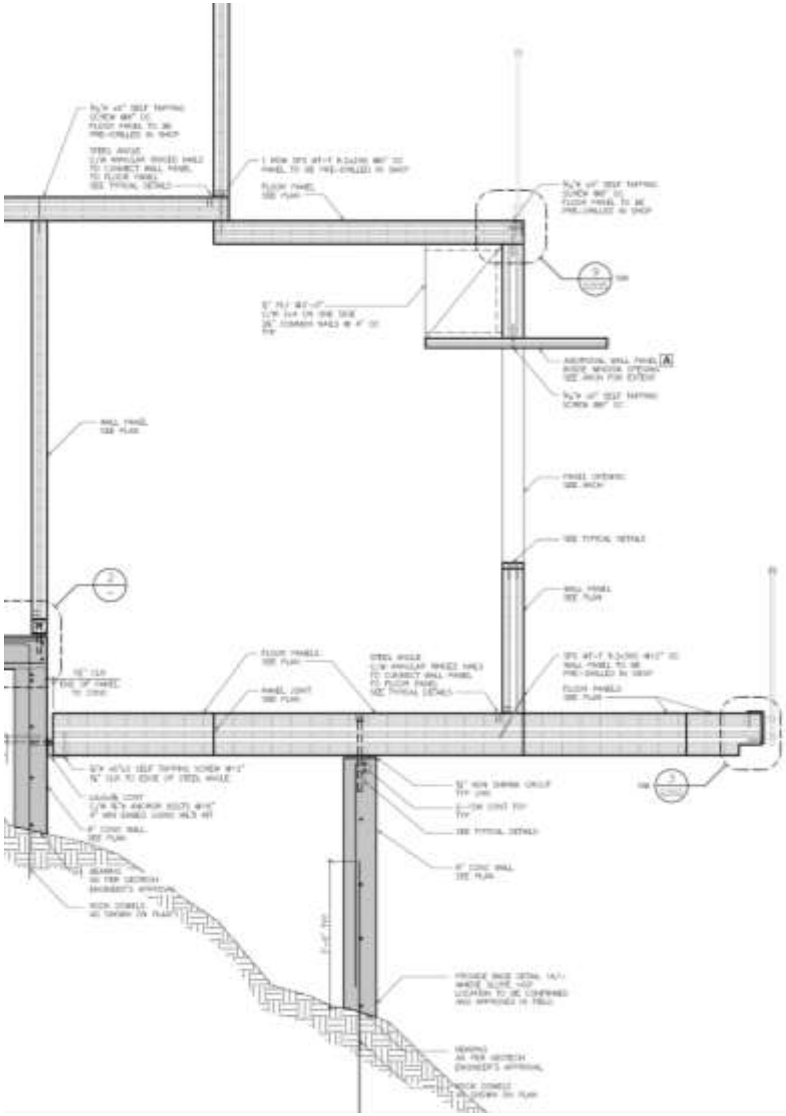
Dowling Residence

West Vancouver

4 (3)-storey
600 m² (6400 SF)
1st in Canada
CLT structure
on concrete base

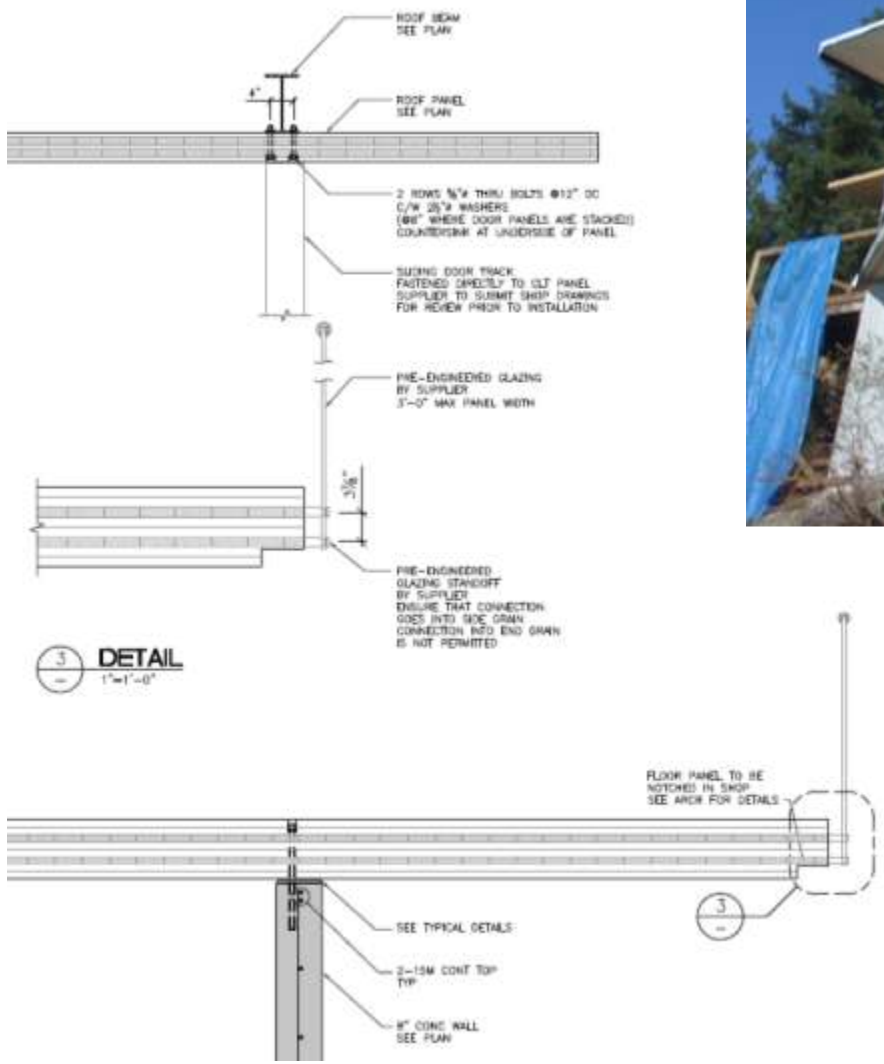
Dowling Residence

West Vancouver



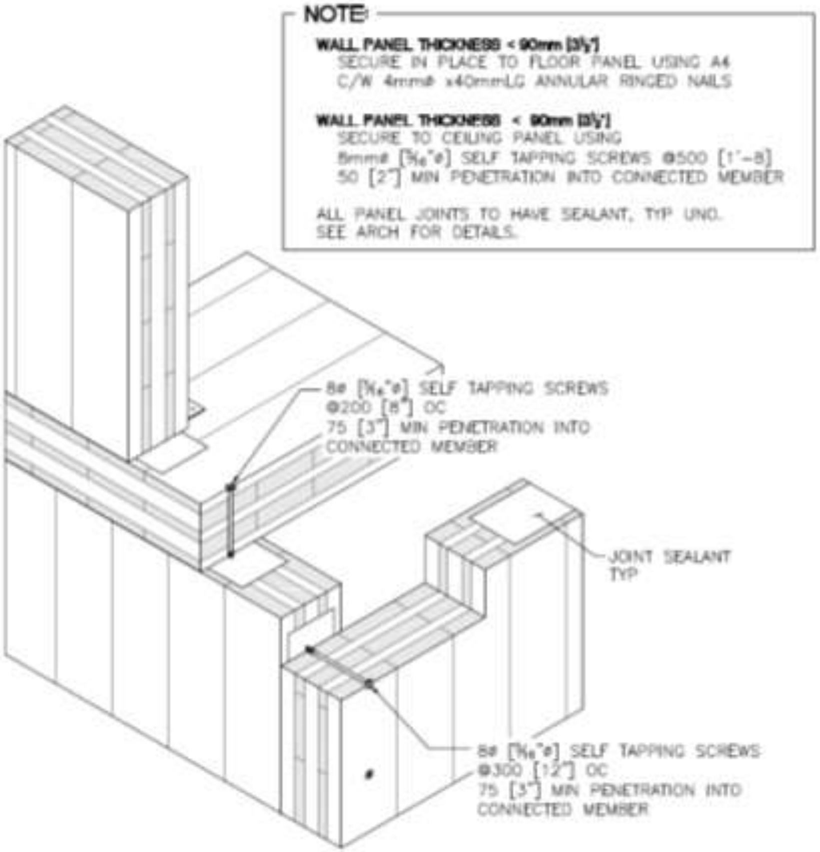
Dowling Residence

West Vancouver



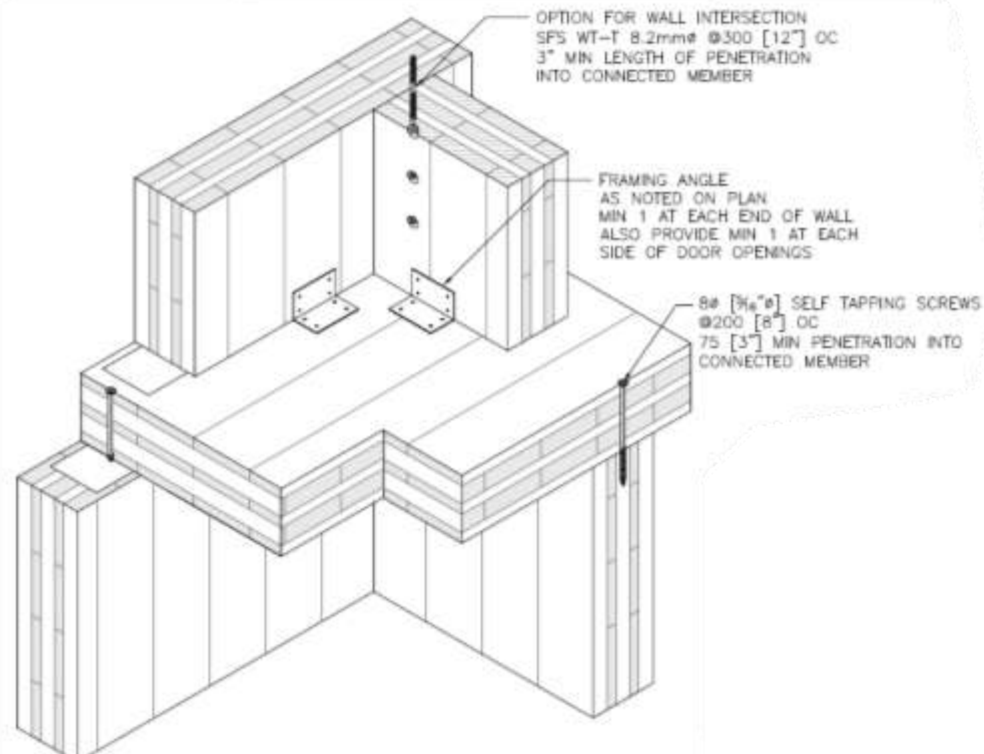
connections CLT to CLT

Dowling Residence



TYPICAL WALLTO FLOOR CONNECTION II

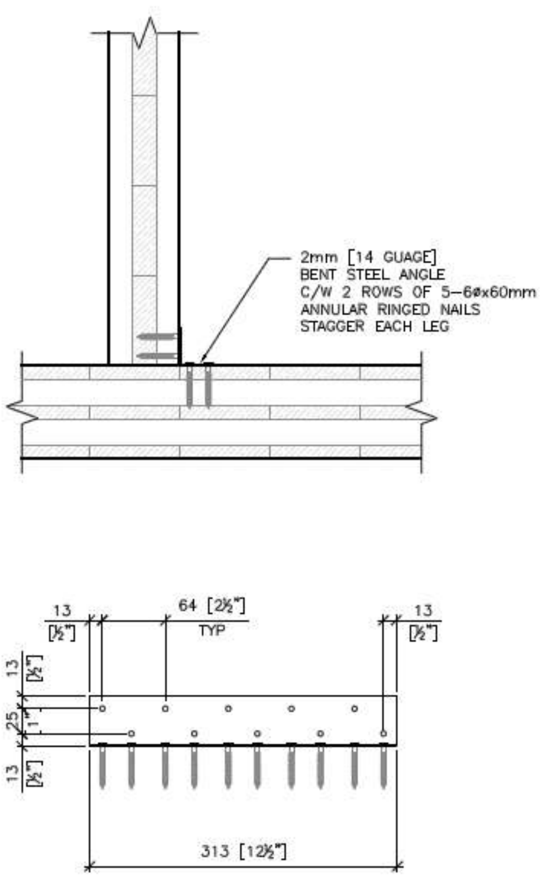
NTS



TYPICAL WALLTO FLOOR CONNECTION I

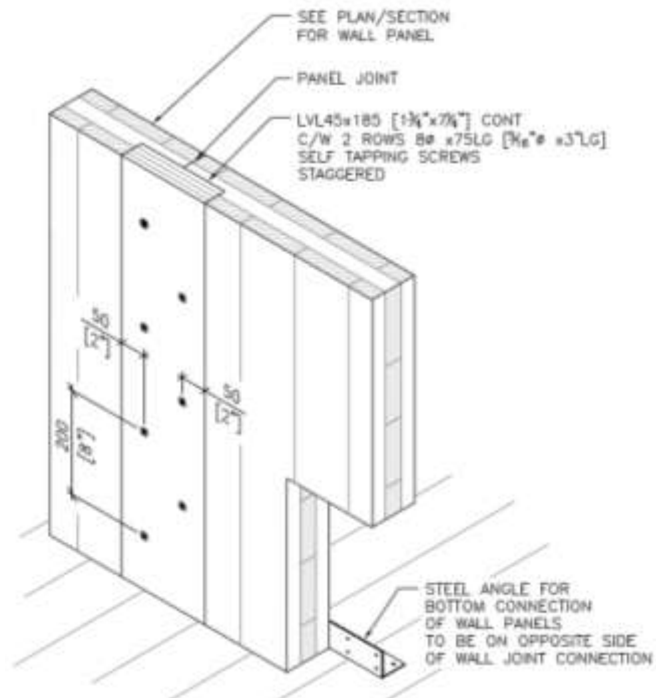
NTS

connections CLT to CLT
Dowling Residence



TYPICAL ANGLE CONNECTION

NTS

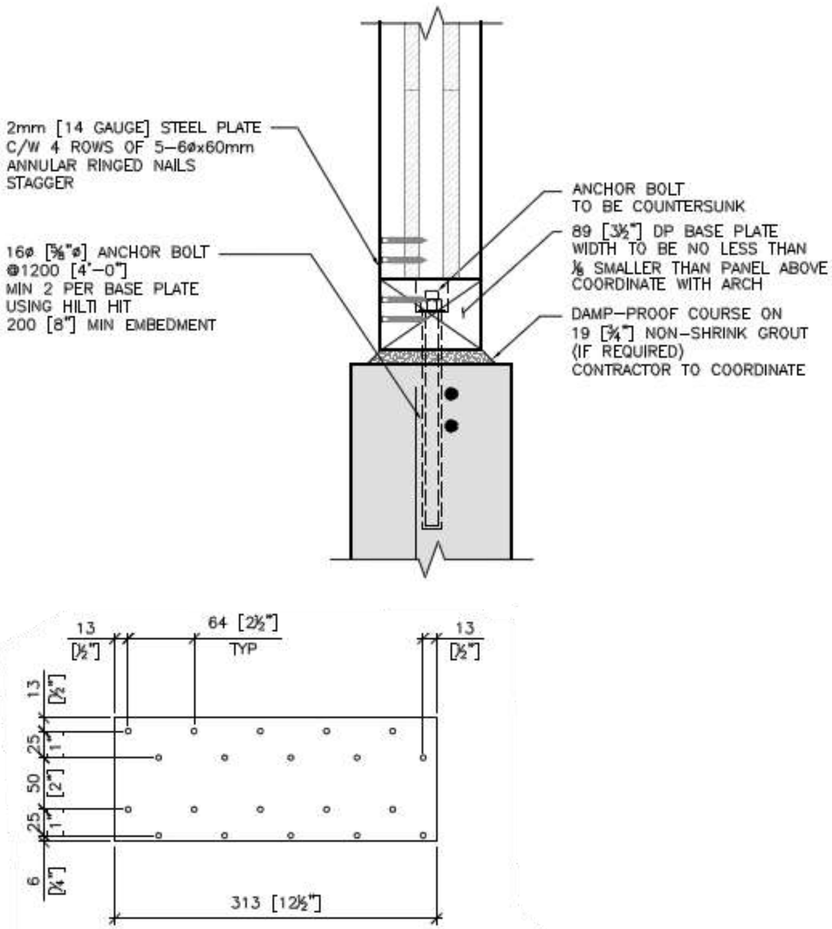


TYPICAL WALL PANEL JOINT

NTS

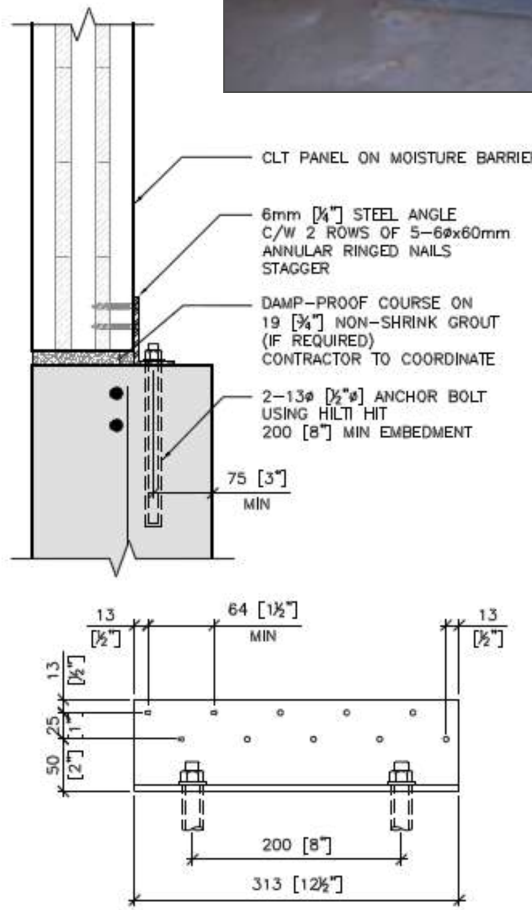
connections concrete

Dowling Residence



TYPICAL BASE PLATE CONNECTION

NTS

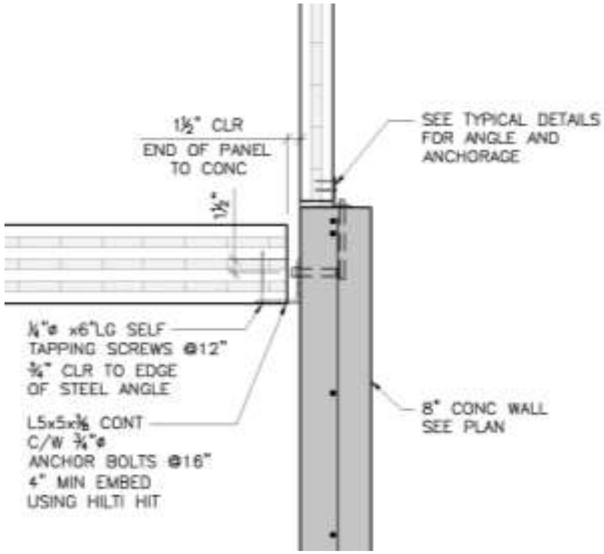


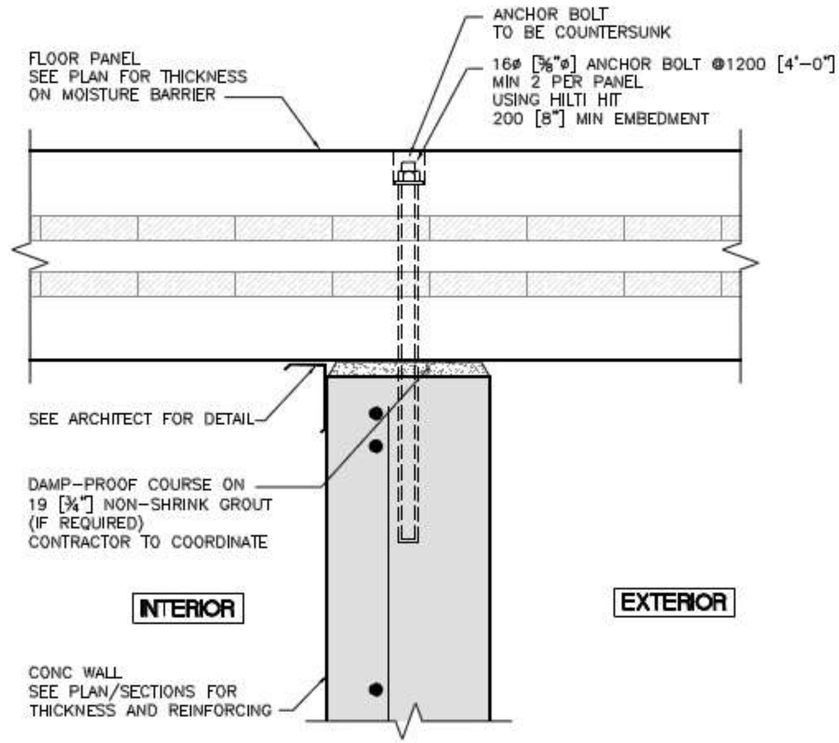
TYPICAL CONCRETE CONNECTION

NTS

connections concrete

Dowling Residence



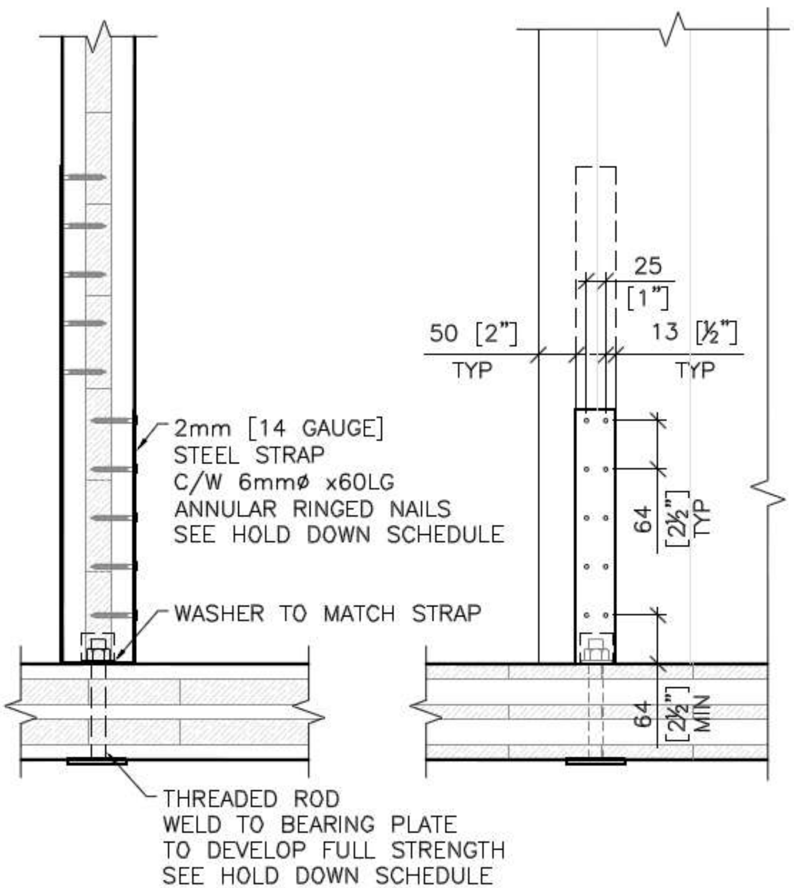


TYPICAL FLOOR PANEL ON CONC WALL

NTS

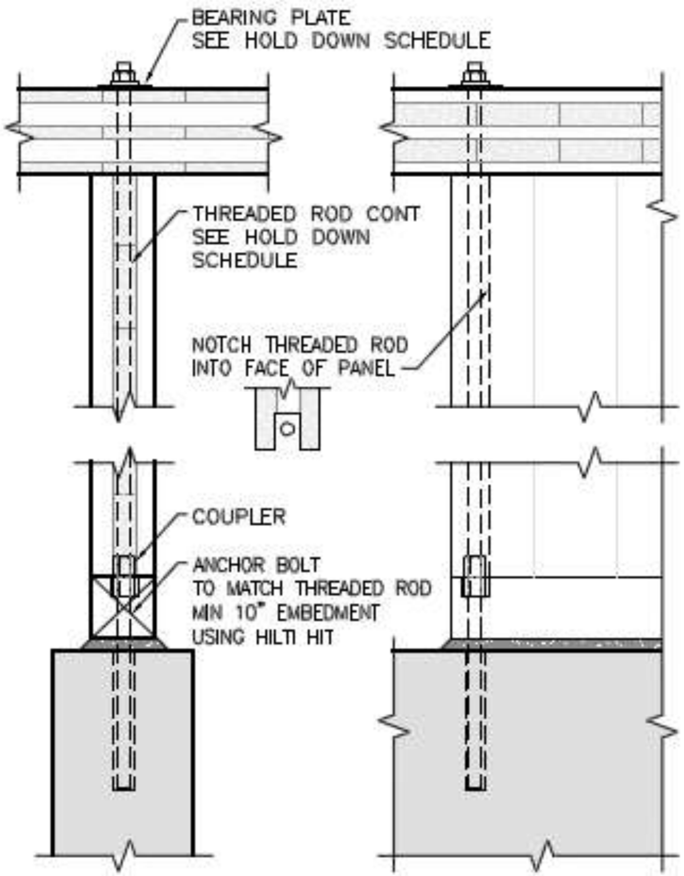
connections hold downs

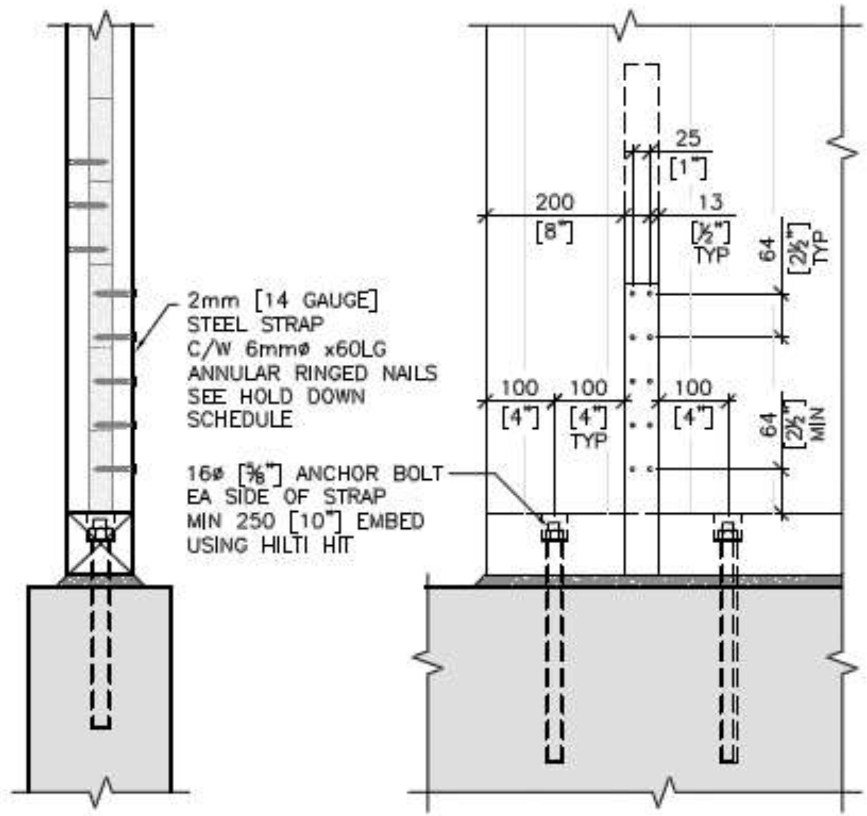
Dowling Residence



connections hold downs

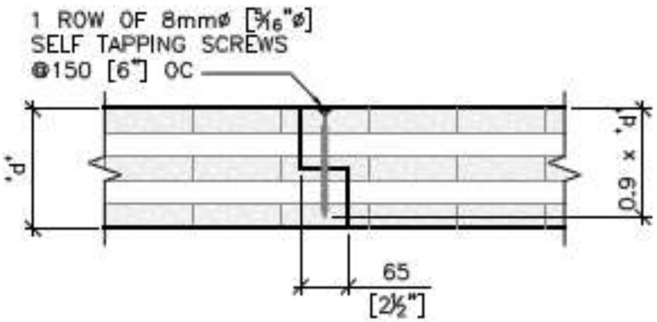
Dowling Residence



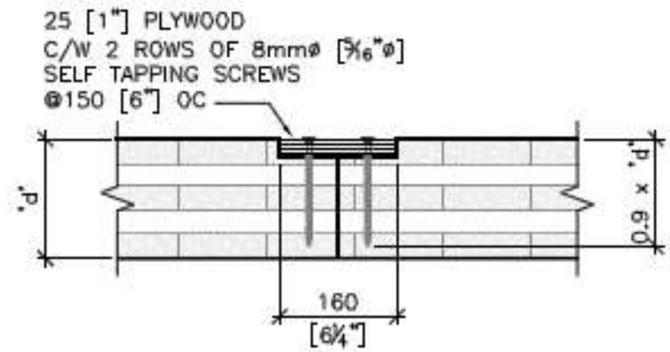


connections floor/roof panel joints

Dowling Residence



JT1 - JOINT SECTION



JT2 - JOINT SECTION

NOTE:

ALL PANEL JOINTS TO HAVE SEALANT.
TYP UNO.
SEE ARCH FOR DETAILS.

TYPICAL FLOOR/ROOF PANEL JOINTS PARALLEL TO MAIN LAYERS

NTS

UBC Bioenergy R&D Project

University of British Columbia

image courtesy of McFarland Marceau Architects

UBC Bioenergy R&D Project

University of British Columbia

20 300 SF
CLT walls + roof deck
glulam moment frame
concrete raft slab

images courtesy of McFarland Marceau Architects

UBC Bioenergy R&D Project

University of British Columbia

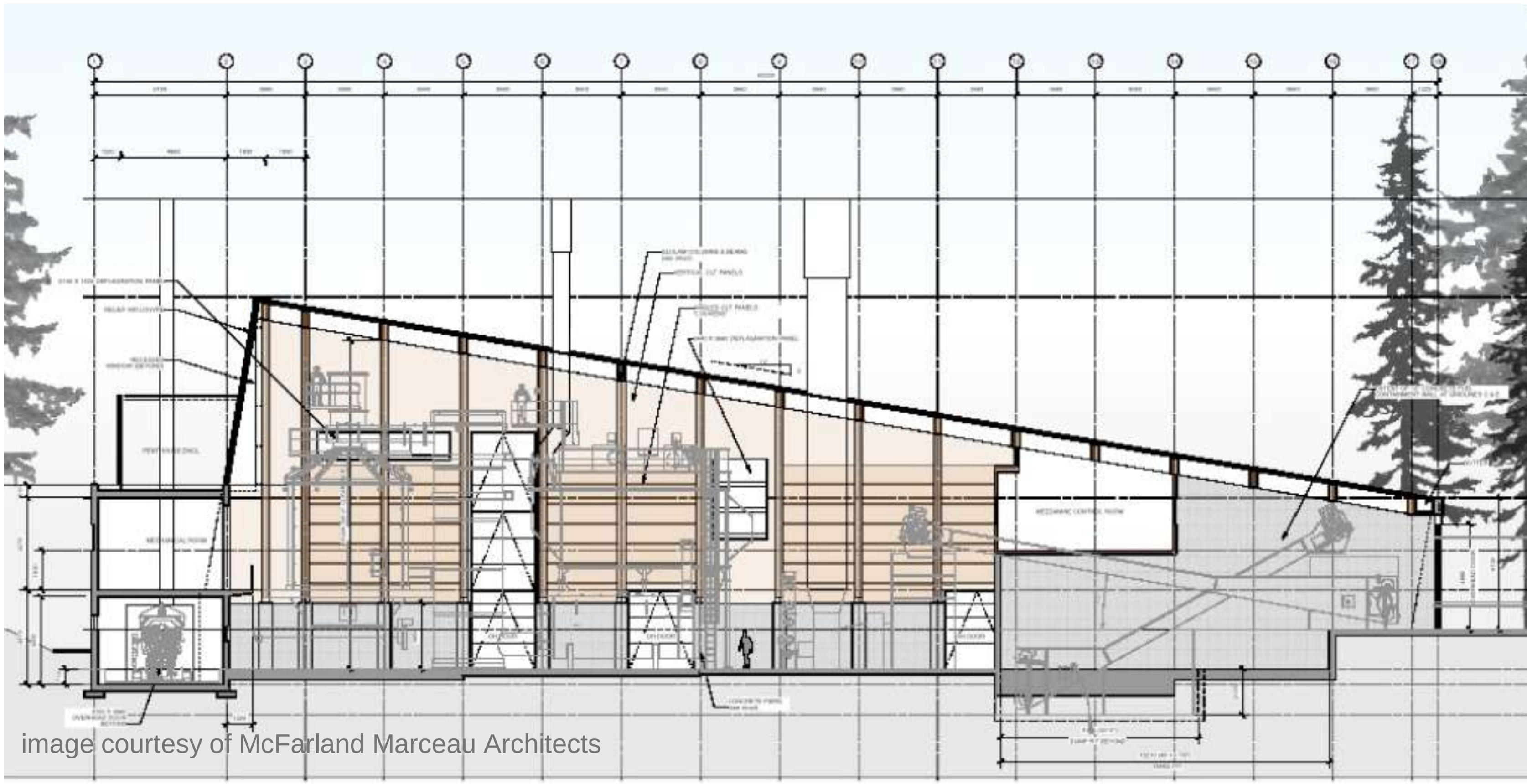
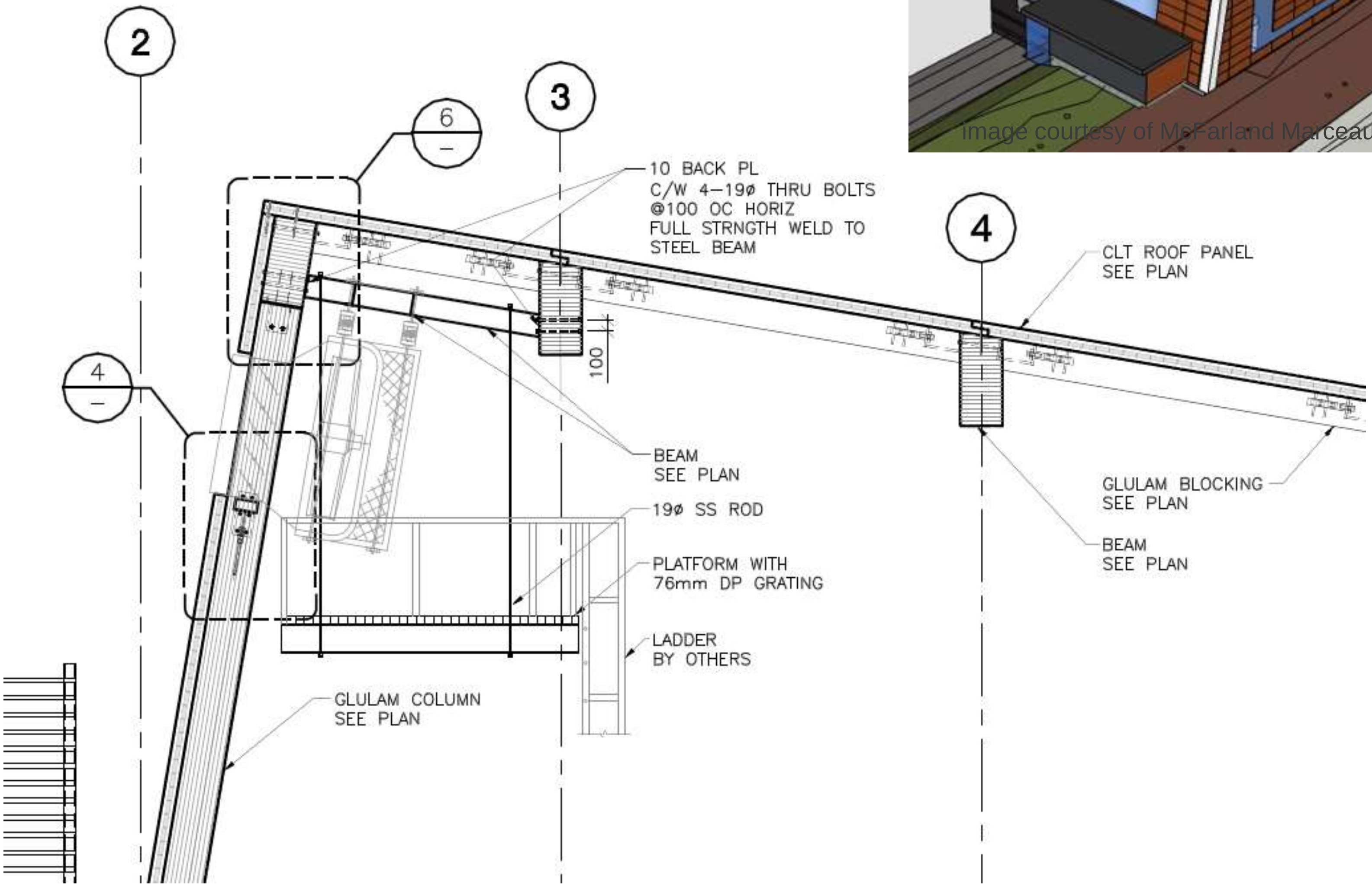


image courtesy of McFarland Marceau Architects

UBC Bioenergy R&D Project

University of British Columbia



Summary and New Approach

- Practical Design & Rules of Thumb
- Codes, Guidelines & Specs
- BC Projects

- Wider approach
  - Influence of Structural Material
  - Energy efficiency
  - CO2 Sequestration
  - Heat Bridges etc.
  - New role for Structural Engineer

CanPHI Canadian Passive House Institute

Passive House with solid wood

Dr. Guido Wimmers

Intelligent Energy Europe

PASSIV HAUS INSTITUT

PASSIVHAUS DIENSTLEISTUNG GmbH

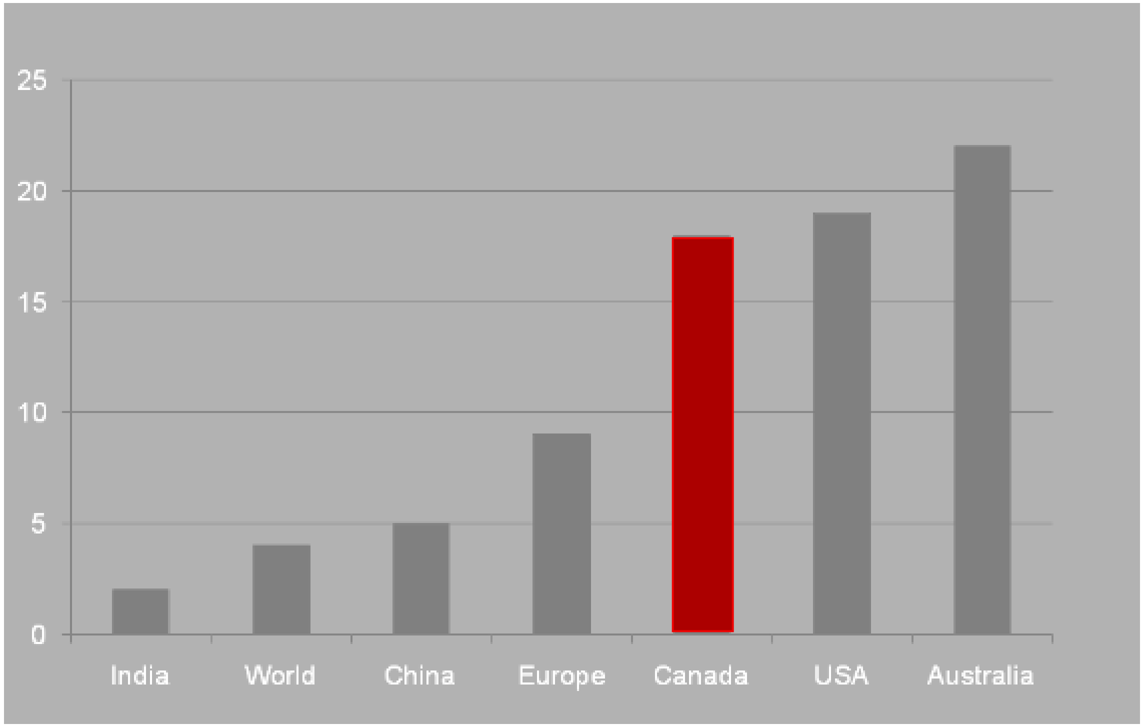
Energieinstitut Vorarlberg

eza! bildung

emissions

- Kyoto protocol: Canadian target was to reduce emissions (based on 1990) by 2007 by **- 6%**

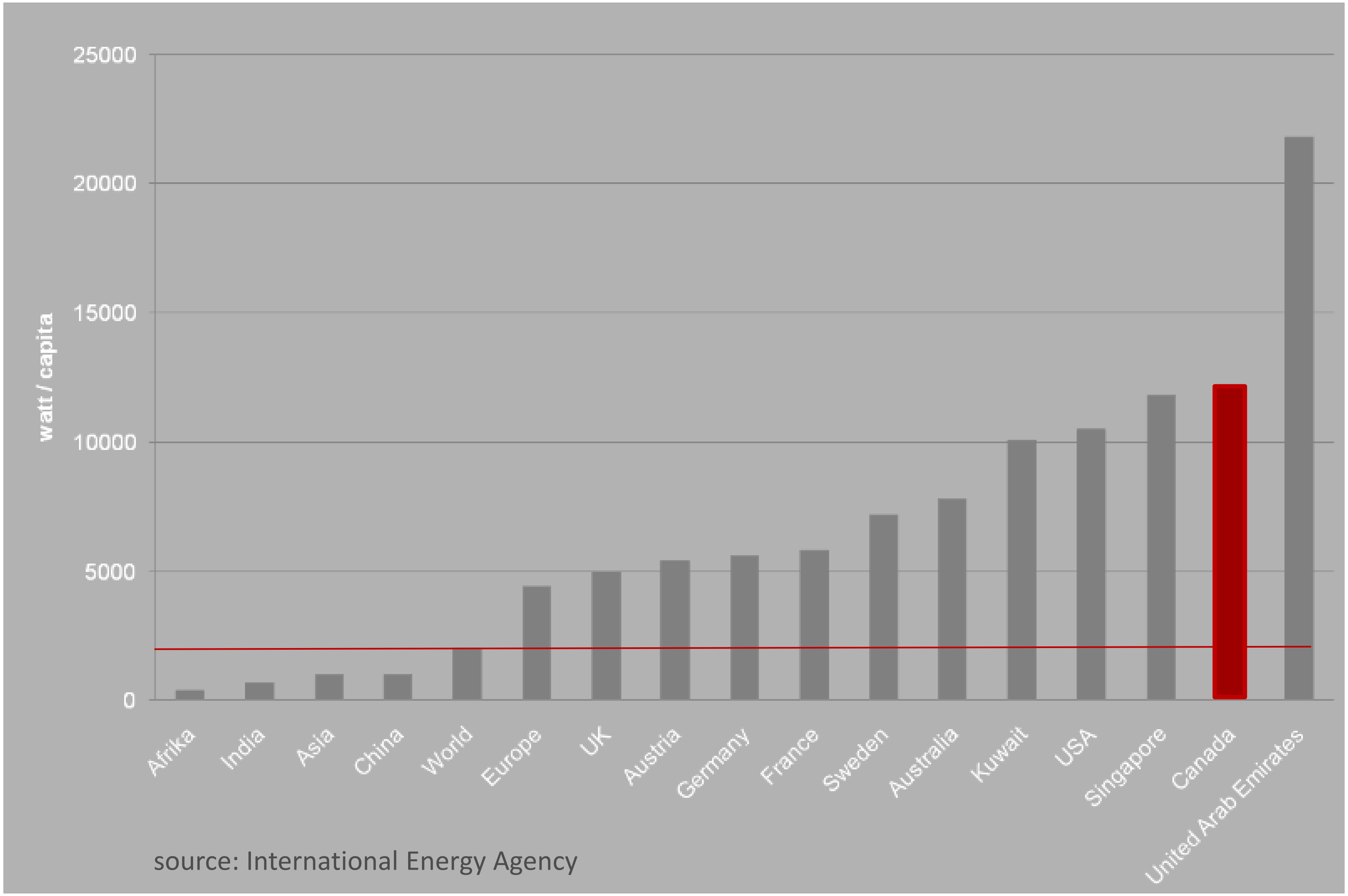
  In fact emissions increased by **+ 27%**



CO2 emissions per capita in tons per year

source: International Energy Agency

primary energy consumption per capita



IMPACTS OF U.S. BUILDINGS ON RESOURCES

40% primary energy use*

72% electricity consumption*

39% CO_2 emissions*

13.6% potable water consumption**

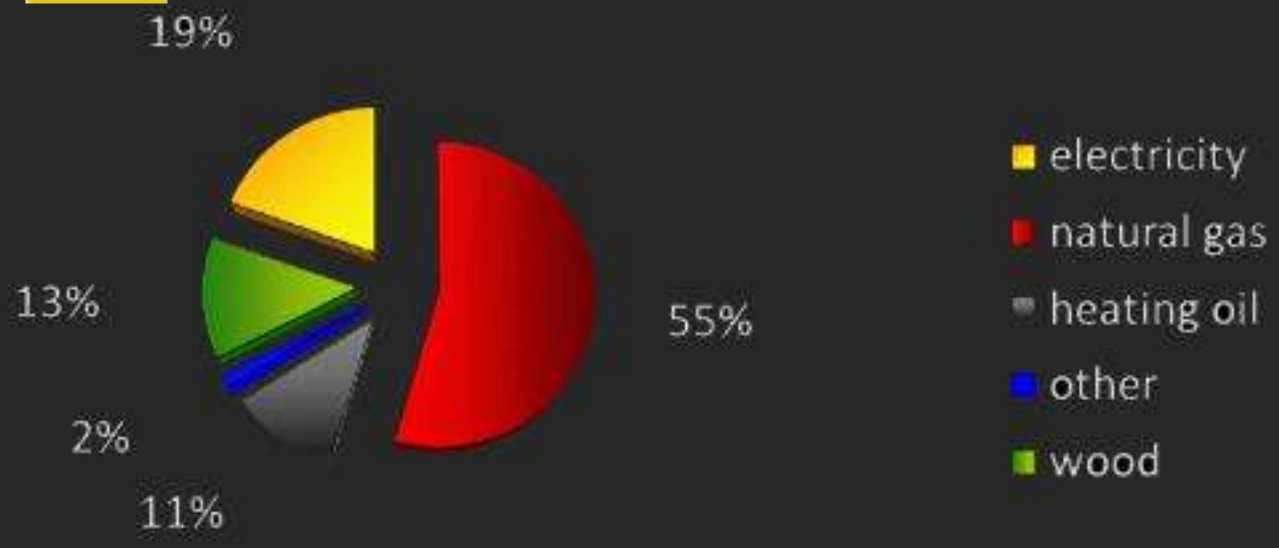
Sources:
*Environmental Information Administration (2008). EIA Annual Energy Outlook.
** U.S. Geological Survey (2000). 2000 data.

priorities

“The energy that buildings use for heating, lighting and cooling is the major component of their environmental impact – approximately 85% of the total life cycle impact for typical office buildings.”

[LEED; Cole & Kernan, 1996; Winistorfer and Chen, 2004; Trusty & Meil, 2000; CORRIM, 2004]

Canada´s total residential space heating energy use

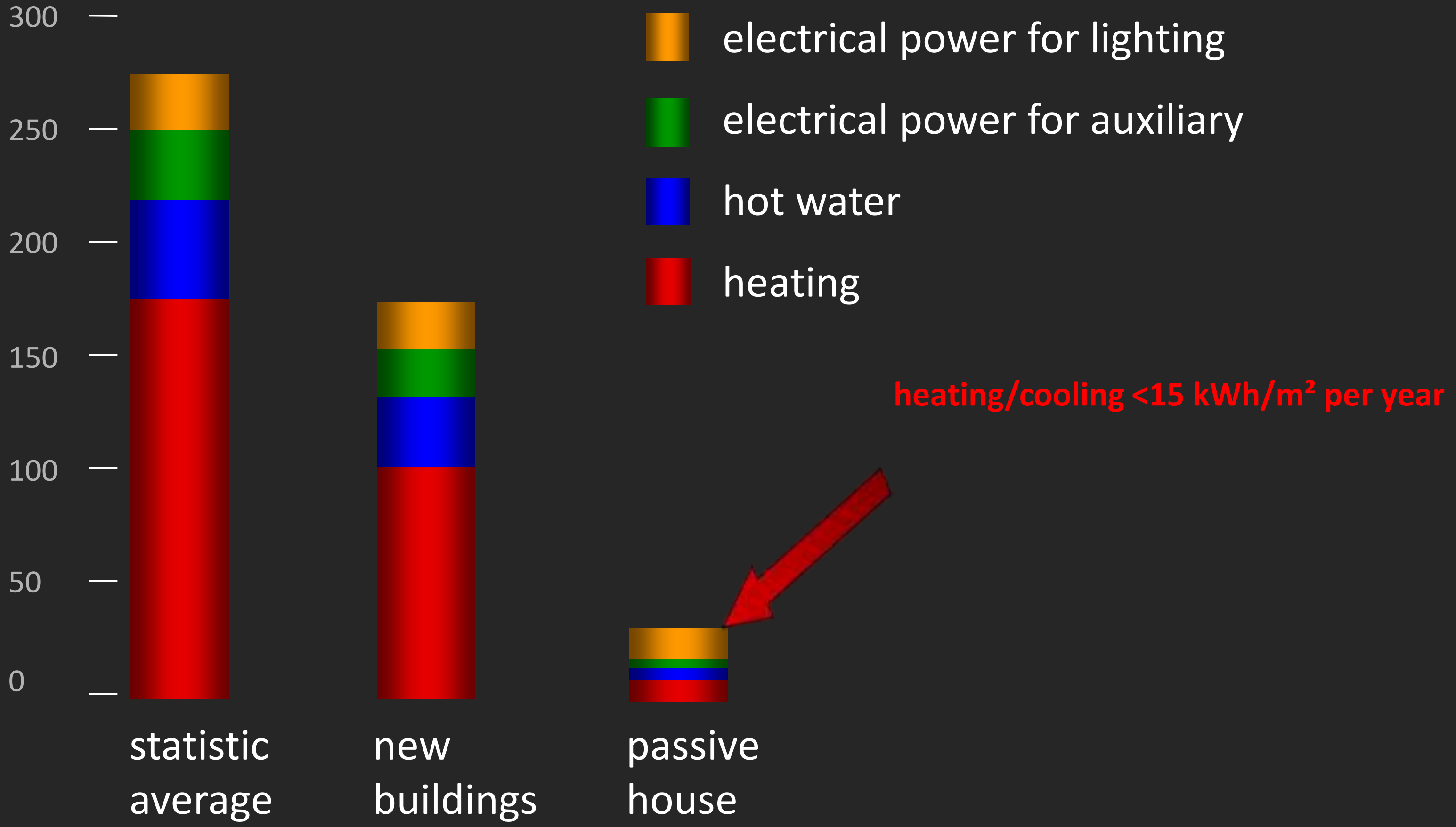


source: Energy Use Data Handbook 2006

- 2/3 provided by fossil energy
- energy use for residential space heating 800 PJ = 222000 million kWh
- total floor space 1500 million m²
- if really every m² is heated

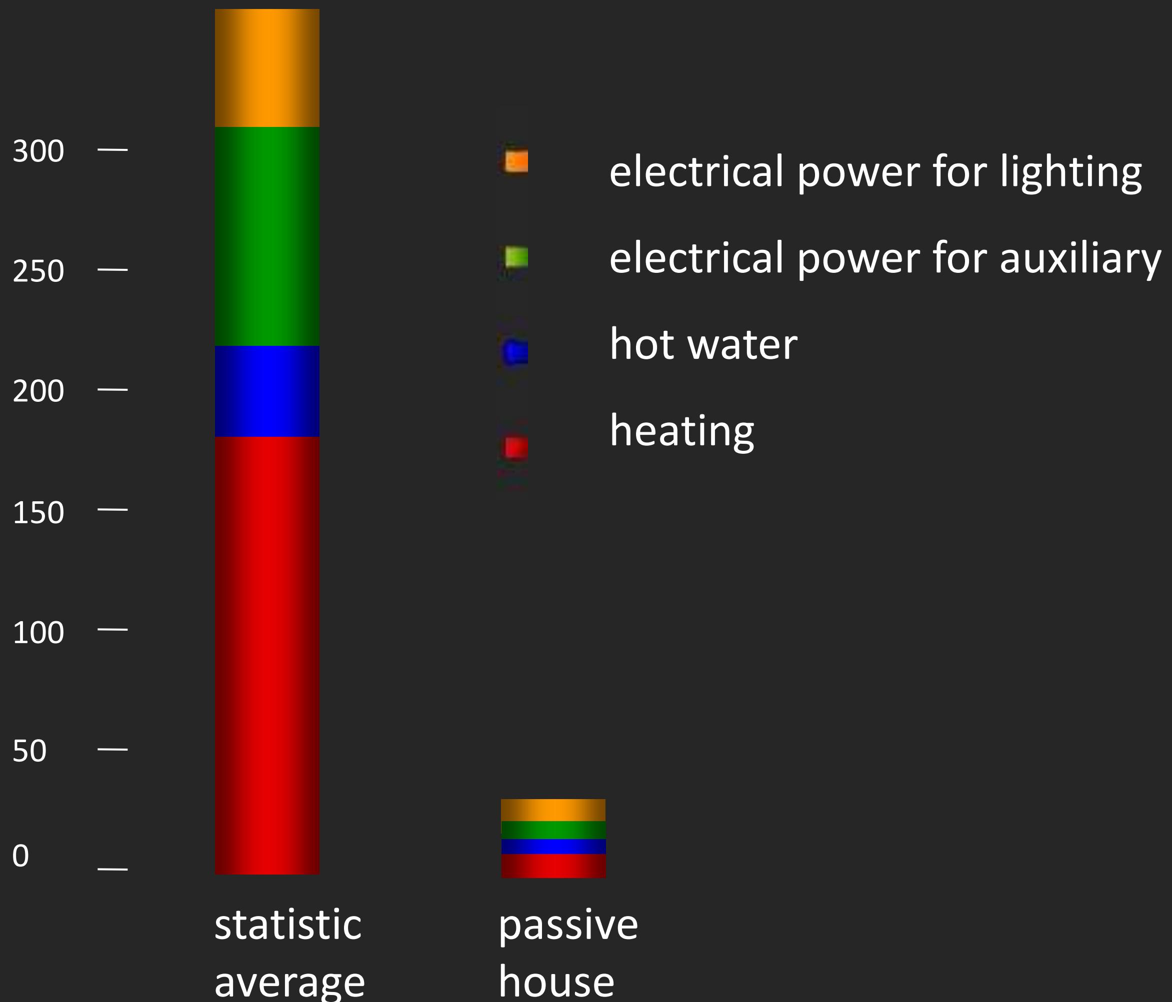
  150 kWh/m²

for residential buildings in kWh/m² per year



Source: NRCan Dec.2005

for commercial buildings in kWh/m² per year



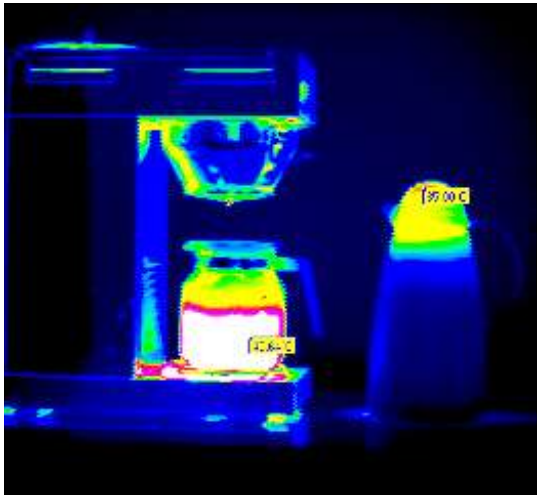
source: Energy Use Data Handbook 2007

the Passive House Standard

- **energy efficient**
- **comfortable**
- **economically** and
- **environmentally friendly** at the same time.
- Passive House is *not a brand, it is a building concept* which is open to all – and which has proved itself in practice.
- Passive House is the leading standard in energy saving in buildings worldwide: The energy saving for heating amounts to over 75 % in comparison with the legally prescribed building standards. The heating costs are very small – high energy prices make no difference to residents of Passive Houses.
- Passive Houses achieve this enormous energy conservation through the use of special energy efficient building elements and ventilation techniques.

Comfort is not impaired, in fact it's even perceptibly improved.

what is a Passive House?



- a Passive House is a **very** energy-efficient building which requires such a small amount of heat that it can be heated mainly by “passive” sources such as incoming sunlight and existing appliances

- heat recovery via a mechanical ventilation system is necessary

what is a Passive House?

- a Passive House still needs some energy, but the specific heat demand is minimal.
  15 kWh/m²year
- specific heat load shall not exceed 10 W/m²
- entire specific *primary* energy demand including domestic electricity must not exceed 120 KWh/m²year
- The PH Standard *should* become a precondition for the Living Building Challenge and for any Net Zero House initiative

Thermal comfort: Influences

Essential factors which influence thermal comfort

- Air temperature
- Surface temperatures
- Local temperature differences (vertical and horizontal)
- Draughts
- Relative air humidity

Source: [EN ISO 7730], IG Passivhaus Deutschland

Author: PHD

Why does CLT fit to Passive House?

Can help to fulfill core requirements of energy efficiency and thermal comfort such as:

- Air tightness
- Thermal bridges
- Thermal mass
- Relative humidity

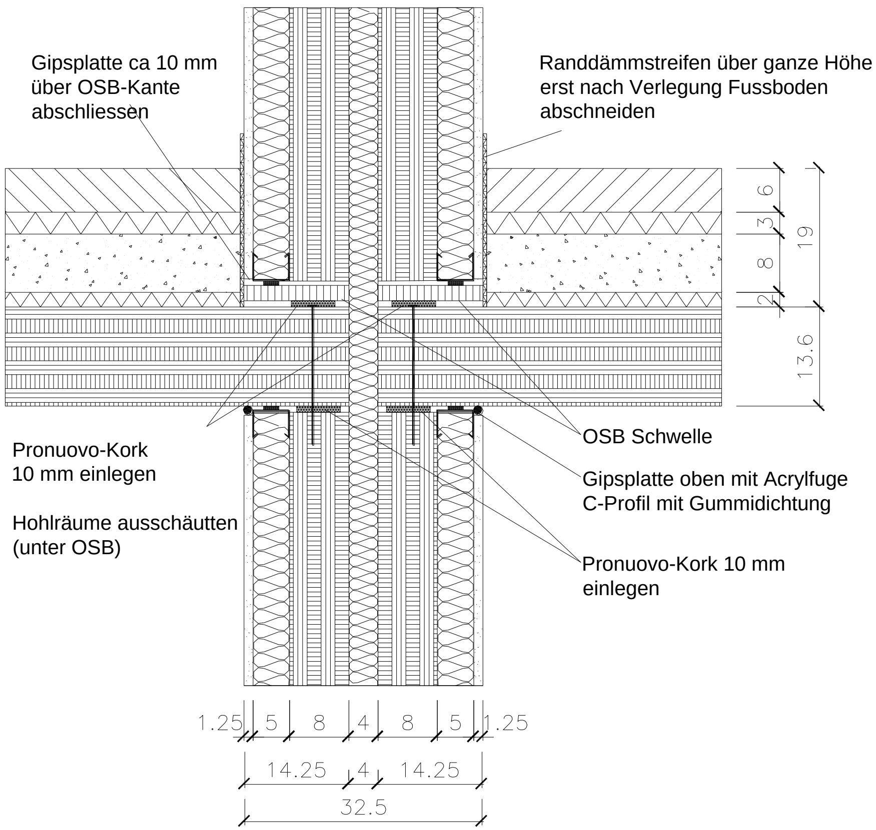
Other positive side effects:

- Noise control
- Humidity management (vapor diffusion)
- Low embodied energy (can replace concrete)

Solid wood Passive House

Univ.-Prof. DDI Michael Flach

Noise control and air tightness



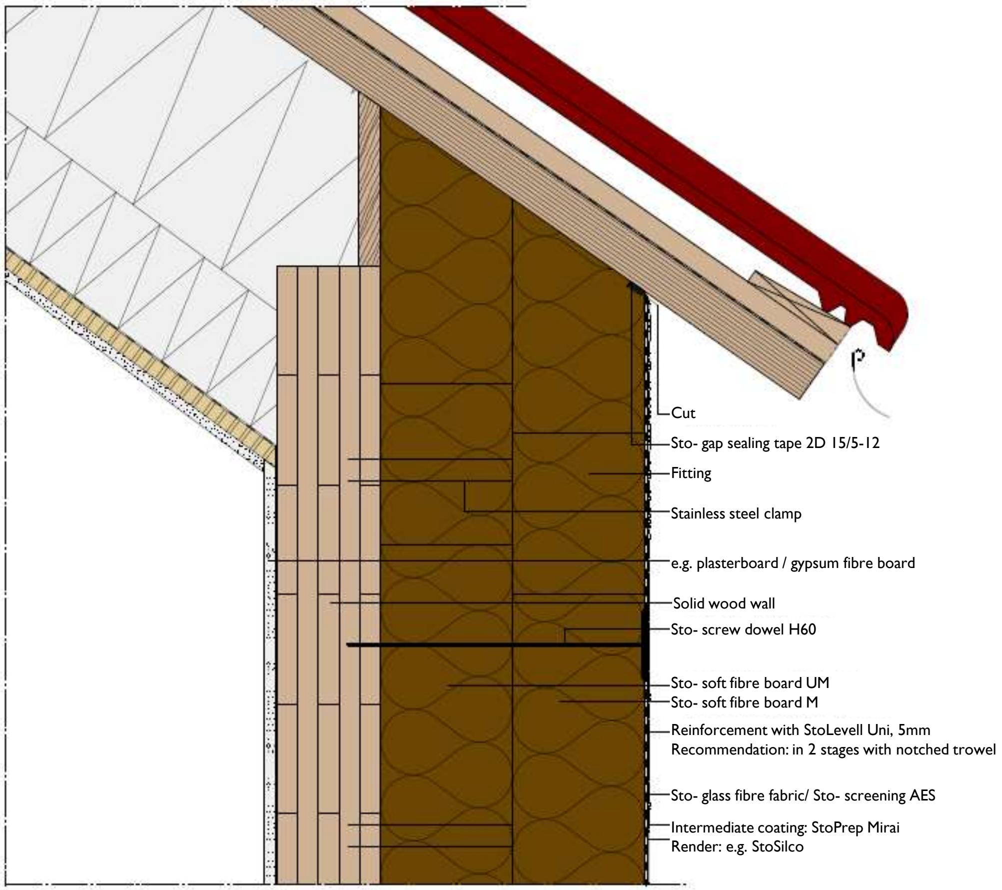
Univ.-Prof. DDI Michael Flach

Roof

Wall

Ground

Transition Eaves/Roof – Solid wood wall



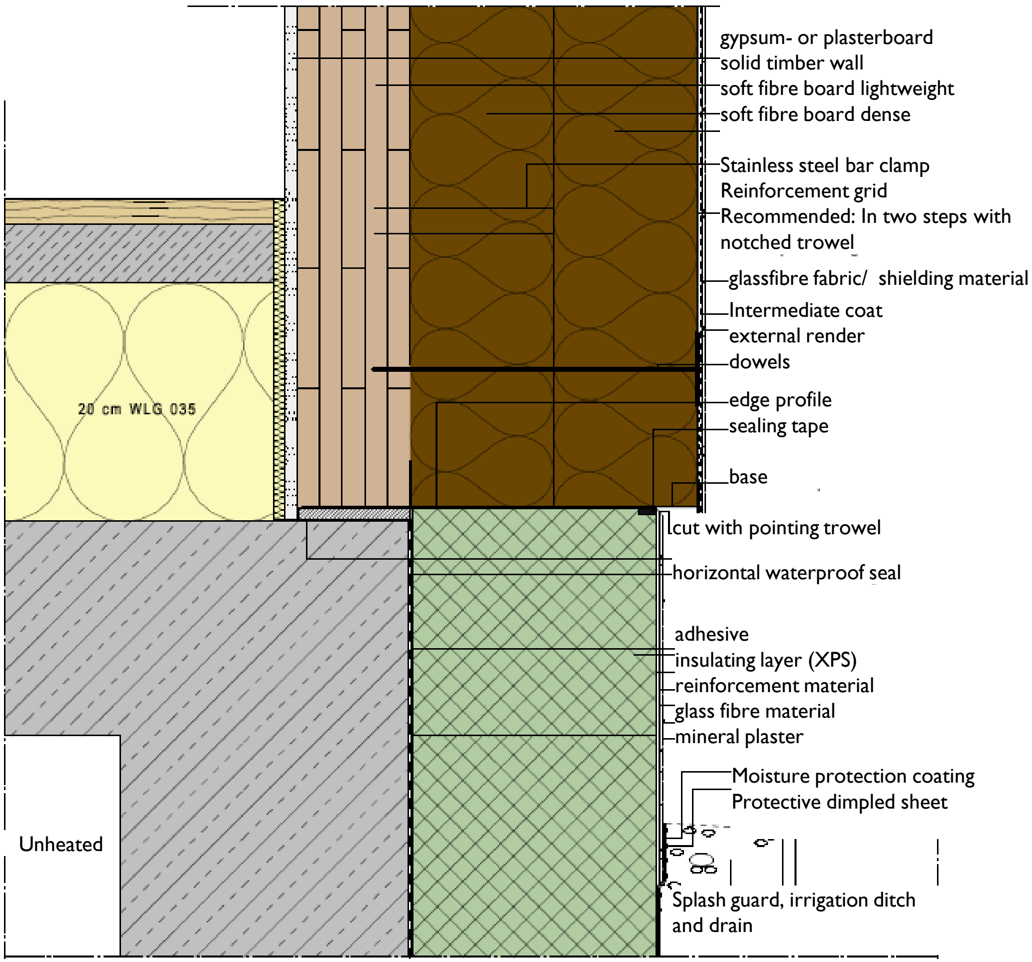
Source: www.sto.de

Author: JM

CanPHI

Roof | Wall | **Ground**

- Connection basement ceiling/ solid timber wall
- The airtight layer should always be indicated!



Source: www.sto.de

Author: JM

Austria House in Whistler

- First Canadian Passive House
- First Canadian solid wood building

window installation

window installation

air tightness test




- pressurization @ 50 Pa = 0.26 air changes/hour
- depressurization @ 50 Pa = 0.30 air changes/hour

CanPHI

Passive House - the future

In 2009 EU passed a directive asking that all states legislate Passive House construction by 2016 for new construction and renovation

Energy efficiency/renewables are now bigger employers in Germany than the entire auto industry (BMW, Opel, Audi, Mercedes, Porsche, VW etc)

No Canadian windows or HRVs or air-sealing products currently come anywhere near Passive House requirements. But what incentive to our manufacturers have to reach these high standards?

Surely builders of Passive Houses should get some financial assistance from federal or provincial governments (as in Alberta).

vancouver.ca/sustainability/documents/PassiveDesignToolKitforHomes.pdf

vancouver.ca/sustainability/documents/58346PassiveKitBookPrt9.pdf

Passive House - the UK perspective

"The application of the Passive House Standard to contemporary construction represents a watershed moment in our relationship with the built environment".

"I would like to see every new home in the U.K. reach the Passive House Standard as the country strives to bring all new homes built after 2016 to the zero-carbon performance standard mandated by our 2008 Climate Change Act".

"It is simply not possible to reach zero carbon homes by 2016, as the U.K. government, has mandated without reference to the work of the Passivhaus Institute in Germany over the last 20 years".

Chris Huhne

Secretary of State for Energy and Climate Change, UK

London, September 2010

- Passive House is *the* world leading standard for environmentally friendly buildings

- Solid wood is a very versatile building product and can be a valuable contribution for Passive House