Hugo Hens

Performance Based Building Design 2

From Timber-framed Construction to Partition Walls

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Contents

1 Timber-framed construction

1.1 In general

In the Low Countries on the North Sea, timber was the common construction material for rural and municipal dwellings until the $13^{th}-14^{th}$ century. Brick construction was an aristocrat's privilege. Many devastating town fires, the sociological fact that bricks stood for wealth and growing wood shortages slowly turned brick building into the new standard.

Timber construction still is the reference in many countries worldwide, like the US, Canada, Norway, Sweden, Finland, Russia, Japan and other countries rich in forests and often with a cold climate. There, the framed type has an important advantage compared to massive construction: it is easy to insulate, which is why even in northwest Europe timber-frame construction has regained popularity, now for passive houses. However, the disadvantages also deserve mentioning: hardly any thermal inertia, air tightness critical and less moisture tolerant than brick construction.

In timber framing, load- and non-bearing outer and partitions walls consist of a framework of timber studs and crossbeams, called plates. The outer wall frames are externally finished with structural sheathing. Where the studs bear all vertical loads and the outer wall ones have also to withstand the wind component, normal to the façade, the sheathing provides overall stiffness against horizontal loading. It also prevents buckling of the studs parallel to their lowest inertia radius. From the three common framing approaches – platform, balloon, post and beam – the platform type, composed of storey-high stud walls and timber floors is the most popular (Figure 1.1).

Construction looks as follows: once the foundations and foundation walls are ready, the ground floor is laid, in humid climates preferably a concrete deck, though in dry climates also timber joists with plywood or OSB (oriented strand board) deck apply, the crosscut end sides being closed with header plates. In such case, ripped half-width standard timber beams form the floor joists with struts at half-span excluding lateral buckling. Then one fixes the bottom plates, after which the studs are nailed and coupled with top plates. To stabilize the frame corners, doubling these is an option. After, a plywood, OSB or stiff insulation board (XPS) sheathing is nailed to the outer wall frames. The joists of the second floor, which are fixed at the top plates then follow. Header plates again close the crosscut end sides and plywood or OSB forms the running surface. The same cycle restarts for the second storey: bottom plate, studs, top plates, sheathing, floor joists, running surface, etc.

A timber framework or rafters, axis to axis at the same distance as the studs, shape the load-bearing roof structure with an external sheathing once more providing stiffness. Timber framing ends with wrapping up the outer walls with waterproof, wind tight building paper, stapled from bottom to top on the sheathing with the higher strips overlapping the lower ones. Platform framing lends itself to modular construction and prefabrication.

From inside to outside the outer wall assembly looks like (Figure 1.2): inside lining (gypsum board); (service cavity); air (always) and vapour (when necessary) retarder; bays between studs filled with insulation (mineral wool or cellulose); plywood, OSB or stiff insulation board sheathing; building paper; outside finish (timber siding, brick veneer, EIFS, etc).

Aside from timber framing, also metal framed construction exists, with metal studs and plates replacing the timber ones.

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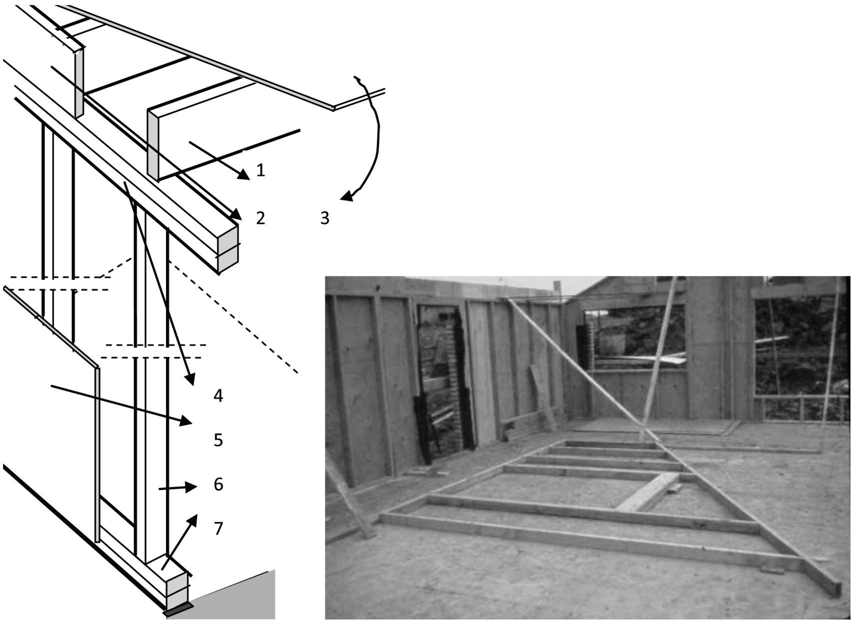


Figure 1.1. Platform type (1: joists, 2: header plate, 3: running surface, 4: top plates, 5: sheathing, 6: studs, 7: bottom plates).

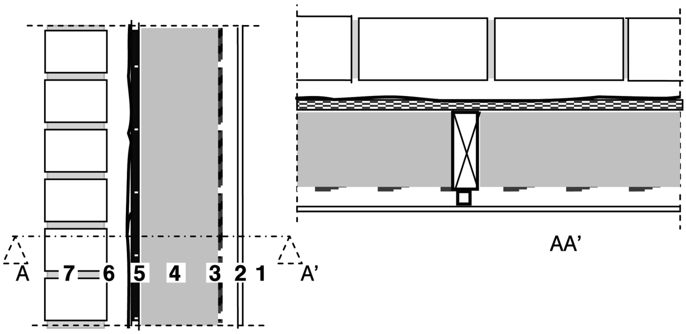


Figure 1.2. Timber-framed outer wall, reference assembly (1: inside lining, 2: service cavity, 3: air and vapour retarder, 4: thermal insulation; 5: sheathing, 6: building paper, 7: outside finish).

1.2 Performance evaluation

1.2.1 Structural integrity

Timber-framed buildings are so lightweight that anchoring in the foundation walls is necessary to prevent displacement under extreme wind load (Figure 1.3).

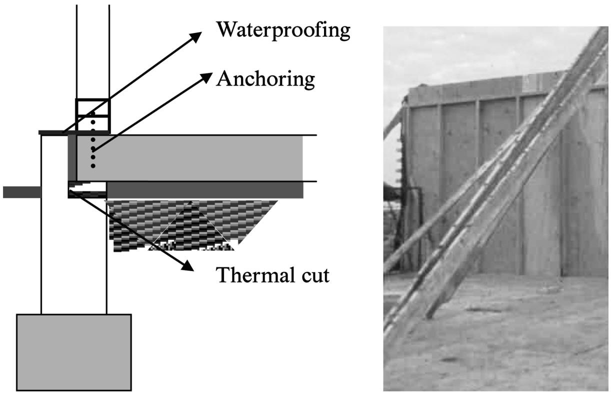


Figure 1.3. Timber-framed construction, anchoring in the foundation walls.

Wind loading and buckling of the outer and partition wall studs demands proper attention. The sheathing or inside finishes block it in the lowest moment of inertia direction. The direction normal to the walls needs a control. Table 1.1 gives the buckling factors vertical loads have to be multiplied by, as a function of the stud's slenderness (i):

$$i = \frac{L}{\sqrt{\frac{I}{A}}} \tag{1.1}$$

with L the effective stud span (in timber framed construction equal to the distance between bottom and top plates), I the moment of inertia around the neutral axis of the combination stud/sheathing (if shear-stiff coupled) and A total active cross section.

If this product gives stresses in the timber beyond acceptable, or, if for a given span the stud's radius of inertia is too low, then two options are left: diminishing the centre-to-centre distance between studs or using deeper ones. The first is disadvantageous in terms of whole wall thermal transmittance whereas the second allows larger insulation thicknesses, thus, a lower whole wall thermal transmittance.

Table 1.2 summarizes the mechanical properties of softwood and plywood. For the stiffness against horizontal loads, the same rules as for massive construction hold: the floors as rigid horizontal decks, at least 3 sheathed or wind-braced walls whose centre planes do not cross in one point, the stiff walls preferentially distributed in a way the resulting wind load vector crosses their stiffness centre.

Table 1.1. Buckling factors (slenderness vertically in steps of 10, horizontally in steps of 1).

Slenderness	0	1	2	3	4	5	6	7	8	9
0	1	1	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.04
10	1.04	1.04	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.08
20	1.08	1.09	1.09	1.10	1.11	1.11	1.12	1.13	1.13	1.14
30	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.22	1.24	1.25
40	1.26	1.27	1.29	1.30	1.32	1.33	1.35	1.36	1.38	1.40
50	1.42	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60
60	1.62	1.64	1.67	1.69	1.72	1.74	1.77	1.80	1.82	1.85
70	1.88	1.91	1.94	1.97	2.00	2.03	2.06	2.10	2.13	2.16
80	2.20	2.23	2.27	2.31	2.35	2.38	2.42	2.46	2.50	2.54
90	2.58	2.62	2.66	2.70	2.74	2.78	2.82	2.87	2.91	2.95
100	3.00	3.06	3.12	3.18	3.24	3.31	3.37	3.44	3.50	3.57
110	3.63	3.70	3.76	3.83	3.90	3.97	4.04	4.11	4.18	4.25
120	4.32	4.39	4.46	4.54	4.61	4.68	4.76	4.84	4.92	4.99
130	5.07	5.15	5.23	5.31	5.39	5.47	5.55	5.63	5.71	5.80
140	5.88	5.96	6.05	6.13	6.22	6.31	6.39	6.48	6.57	6.66
150	6.75	6.84	6.93	7.02	7.11	7.21	7.30	7.39	7.49	7.58
160	7.68	7.78	7.87	7.97	8.07	8.17	8.27	8.37	8.47	8.57
170	8.67	8.77	8.88	8.98	9.08	9.19	9.29	9.40	9.61	9.61
180	9.72	9.83	9.94	10.05	10.16	10.27	10.38	10.49	10.60	10.72
190	10.83	10.94	11.06	11.17	11.29	11.41	11.52	11.64	11.76	11.88
200	12.00	12.12	12.24	12.36	12.48	12.61	12.73	12.85	12.98	13.10
210	13.23	13.36	13.48	13.61	13.74	13.87	14.00	14.13	14.26	14.39
220	14.52	14.65	14.79	14.92	15.05	15.19	15.32	15.46	15.60	15.73
230	15.87	16.01	16.15	16.29	16.43	16.57	16.71	16.85	16.99	17.14
240	17.28	17.42	17.57	17.71	17.86	18.01	18.15	18.30	18.45	18.60

Table 1.2. Mechanical properties of softwood and plywood.

Property			Softwood			Plywood	
			Class 1	Class 2	Class 3	// fibres outer laminates	+ fibres outer laminates
Modulus of elasticity		MPa					
// fibres				11 000		7 000	
⊥ fibres				300		3 000	
Shear modulus		MPa		500			
Allowed stress							
Bending	// fibres	MPa	7	10	13		
	⊥ plywood	MPa				13	5
	// plywood	MPa				9	6
Tension	// fibres	MPa	0	8.5	10.5		
	// plywood	MPa				8	4
Compression	// fibres	MPa	6	8.5	11		
	⊥ fibres	MPa	2	2	2		
	⊥ plywood	MPa				3	3
	// plywood	MPa				8	4
Shear	// fibres	MPa	0.9	0.9	0.9		
	⊥ plywood	MPa				1.8	1.8
	// plywood	MPa				0.9	0.9

1.2.2 Building physics: heat, air, moisture

1.2.2.1 Air tightness

Air tightness of timber-framed envelopes is not taken for granted. The outside finish, the building paper, the sheathing, as well as the insulation, all are air-permeable. Contributing factors are, for the building paper, the overlaps between the strips, for the sheathing the joints between boards and for the thermal insulation the material itself and the gaps between insulation, studs and plates. It is the inside finish to guarantee air-tightness. Non-perforated gypsum board linings without cracks between boards have an air permeance of $(K_a) \approx 3.1 \cdot 10^{-5}\ \Delta P_a^{-0.19}$. For an air pressure difference of 10 Pa, that value limits air leakage to 0.43 $m^3/(m^2 \cdot h)$. However, when sockets and others perforate the lining and cracks form between boards, this value may increase by a factor of 10, which is why inclusion of an additional air barrier deserves recommendation. In moderate and cold climates, one used a PE-foil, stapled against the timber frame, preferentially with a service cavity left between foil and inside lining. Recently, OSB with taped joints emerged as an alternative (Figure 1.4). But also with additional air barrier, perfect air-tightness is hard to realize. Even excellent workmanship did not result in tested air leakages below 3 $dm^3/(m^2 \cdot h)$ at 1 Pa air pressure difference. In hot and humid climates, it is up to the outside finish to guarantee air-tightness.

Figure 1.4. Taped OSB as air barrier.

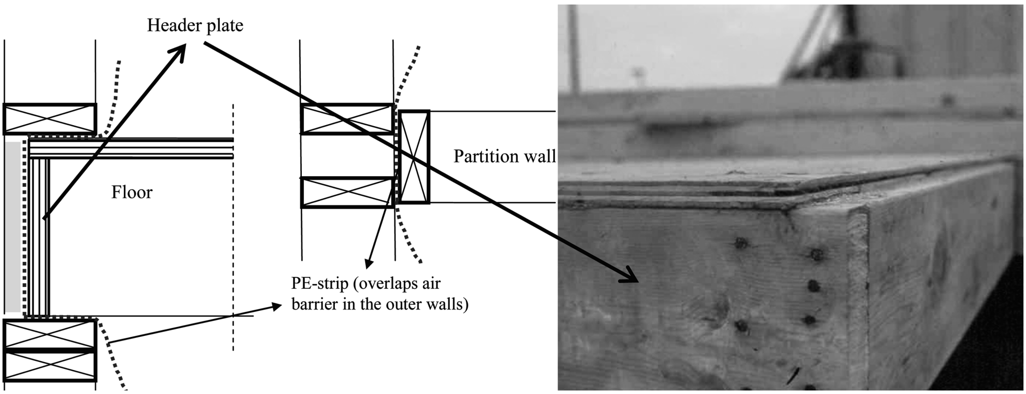


Figure 1.5. Timber-framed construction: caring for a continuous air barrier in the envelope.

Also three-dimensionally, a timber-framed construction offers a network of leaks. Via the junctions with the envelope, outside air may permeate partition walls, while conversely inside air can flow to the outside through the sockets in the partitions. At each floor level, air may flow façade to façade between the joists, a phenomenon causing unexpectedly high heat losses, quick ceiling soiling, and mould where the outside air enters. All this demands an envelope with continuous air barrier. Therefore, the following recommendations prevail: (1) include PE-strips at each floor between header plate and header insulation, (2) fix PE-strips in all junctions between outer and partition walls, (3) tape the overlaps to the air barrier (Figure 1.5).

Fully filling the space between sheathing and air barrier prevents air looping along the thermal insulation. A hotbox test on a two meters high timber framed wall insulated with 8 cm thick XPS-boards demonstrated that partial fills are critical. These are too stiff to link up perfectly with studs, plates, sheathing, and inside lining, creating leaks across and air layers at both sides of the insulation that way. At a temperature difference of 18.7 °C there was no uniform heat loss of 4.5 W/m^2 but large differences between the flow rates up and down the inside and outside surface were noted, see Table 1.3.

Table 1.3. Hot box test: heat flow rate across a timber-framed wall ($U_o = 0.24$ W/(m$^2 \cdot$ K)).

Height m	**Heat flow rate** W/m^2	
	Outside surface	**Inside surface**
1.7	30.9	3.7
0.3	5.7	11.5

The reason is air looping, with cold air rising at the warm side of the insulation, warm air falling at the cold side, changeover from warm to cold on top of the insulation and changeover from cold to warm down the insulation. The data also suggest that thermal stack between hot and cold box activates outflow up, and inflow down the wall.

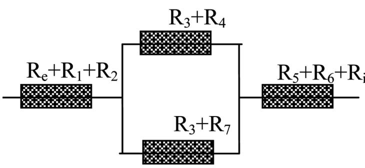
The building paper wrap should guarantee wind-tightness.

1.2.2.2 Thermal transmittance

The discussion relates to outer walls only. For roofs and floors, reference is made to the chapter on floors in Performance Based Building Design 1 and the chapters that follow on roofs. As always, the clear and whole wall thermal transmittances (U) differ, the last accounting for studs, top and bottom plates. In the case of an airtight outer wall, the series/parallel circuit of Figure 1.6 allows a fair guess of the whole wall thermal transmittance, as do also the following linear thermal transmittances (ψ):

Stud	Bottom plate	Top plates
$\psi = 0.017$ W/(m $\cdot$ K)	$\psi = 0.010$ W/(m $\cdot$ K)	$\psi = 0.023$ W/(m $\cdot$ K)

With mineral wool or cellulose as thermal insulation and a brick veneer as outside finish, the thicknesses of Table 1.4 give whole wall thermal transmittances of 0.4, 0.2 and 0.1 W/(m$^2 \cdot$ K) for 40 and 60 cm centred studs.



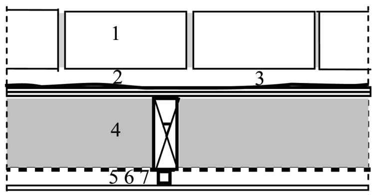


Figure 1.6. Timber framed wall as series/parallel circuit.

Table 1.4. Timber framed outer wall: insulation thicknesses (first number using ψ's, second according to series/parallel circuit).

***U*-value** W/(m$^2 \cdot$ K)	**Insulation thickness in cm**			
	40 cm centred studs		**60 cm centred studs**	
	MW	**Cellulose**	**MW**	**Cellulose**
0.4	8/8	8/9	7/8	8/8
0.2	23/21	24/22	20/20	22/21
0.1	80//46	86/48	60/44	64/46

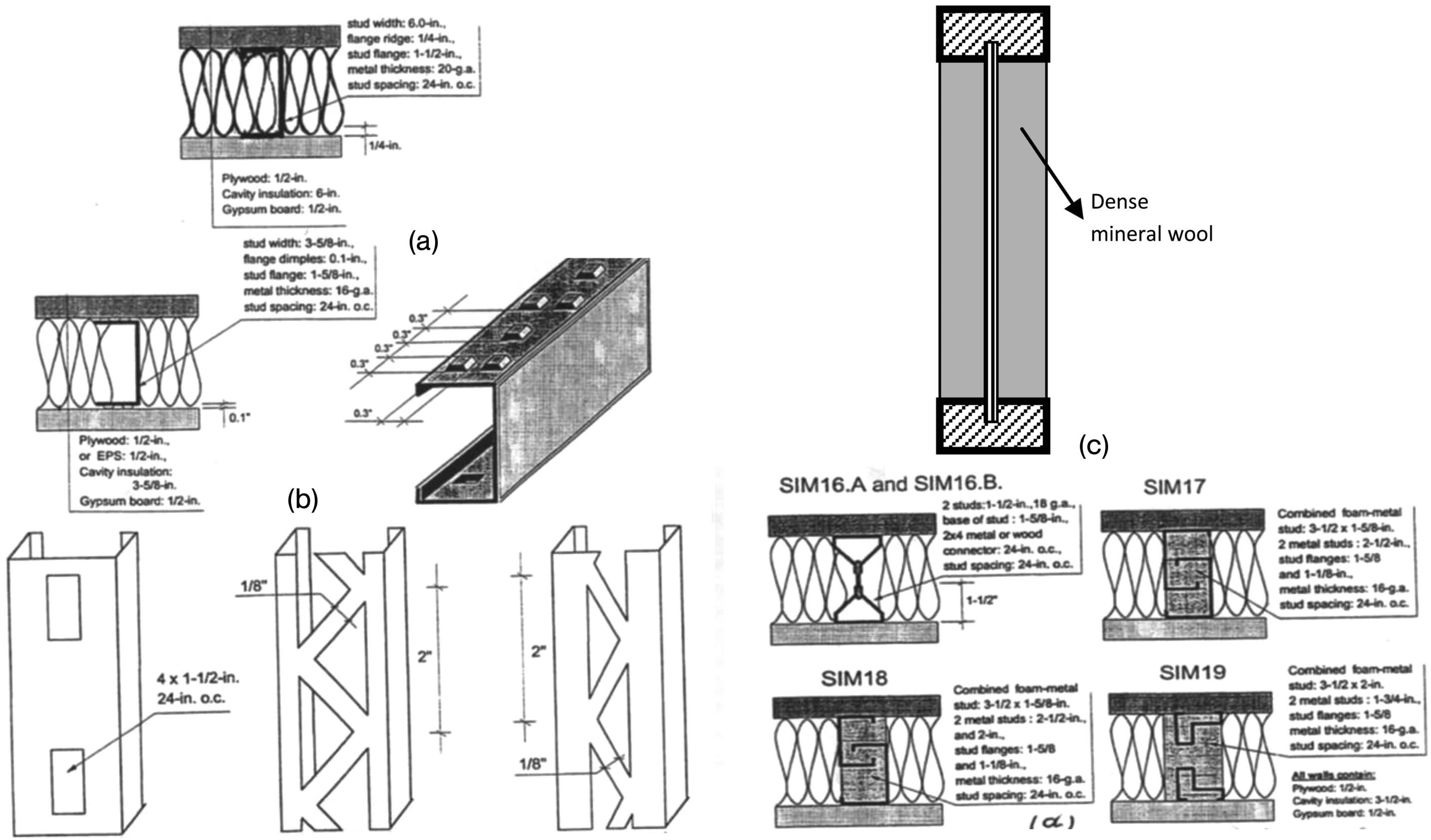


Figure 1.7. Top right engineered timber stud.
(a), (b), (c) are the steel shape studs Table 1.5 is based on.

For the values 0.4 and 0.2 $W/(m^2 \cdot K)$ both methods fit. Yet, for a value 0.1 $W/(m^2 \cdot K)$, the gap is manifest, showing that such low value demands a three-dimensional calculation. 0.2 $W/(m^2 \cdot K)$ gives wall thicknesses touching an acceptable 40 cm. Instead, 0.1 $W/(m^2 \cdot K)$ needs economically questionable thicknesses. The use of engineered studs and plates (Figure 1.7) gives some relief.

With metal frames, thermal bridging effects are more pronounced, with the Figure 1.6 circuit giving no reliable results anymore. Only measurement or three-dimensional calculations do. Take the first wall in Table 1.5. Its studs consist of cold-formed U-steel shapes with wall thickness 1.2 mm. Compared to the clear wall thermal resistance, the whole wall value drops by 38.2%, while timber studs limit that drop to 8.8%.

XPS as sheathing material, plus a smaller contact area between sheathing and steel studs or the use of perforated or thermally cut steel shapes gives the best results. The last bring the whole wall thermal transmittance in line with timber-framed walls.

In addition, the impact of workmanship when insulating the bays has been studied experimentally. Figure 1.8 shows some typical imperfections, while Table 1.6 lists their measured effect on the whole wall thermal transmittance. Increase peaks when air looping develops as is the case with narrowly cut insulation, creating 50 mm wide leaks at both studs.

Table 1.5. Clear and whole wall thermal resistance of the steel framed walls of Figure 1.7.

Assembly 61 cm centres	R_0 $m^2 \cdot K/W$	R Measured $m^2 \cdot K/W$	R_1 Calculated $m^2 \cdot K/W$	$\Delta R/R_0$ %
U-steel shapes 9.2 cm deep, plywood sheathing (Figure 1.7a)	2.25	1.39		38.2
U-steel shapes 9.2 cm deep, 2.5 cm XPS-sheathing	3.10	2.41		22.3
Steel shapes with met nipples 8.9 cm deep, plywood sheathing (Figure 1.7b)	2.25		1.54	31.6
Perforated steel shapes 9.2 cm deep, plywood sheathing (Figure 1.7c)	2.25		1.74	22.7
Perforated steel shapes 9.2 cm deep, 2.5 cm XPS-sheathing	2.81		2.42	14.0
Steel shapes with thermal cut, 8.9 cm deep, plywood sheathing (Figure 1.7d)	2.25		2.10	7.0

Table 1.6. Whole wall thermal transmittance in case of workmanship inaccuracies.

Timber studs 60 cm centre, 15 cm MW, imperfections of Figure 1.8	U_{meas} Measured $W/(m^2 \cdot K)$	U Reference $W/(m^2 \cdot K)$	$\Delta U/U$ %
None	0.230	0.230	0
Boards too strongly pressed against the studs	0.238	0.230	3.5
Insulation carelessly cut, wedge-shaped at studs	0.263	0.230	14.3
Insulation narrowly cut, 50 mm leak at one of the studs	0.246	0.230	7.0
Insulation narrowly cut, 50 mm leaks at both studs	0.350	0.230	50

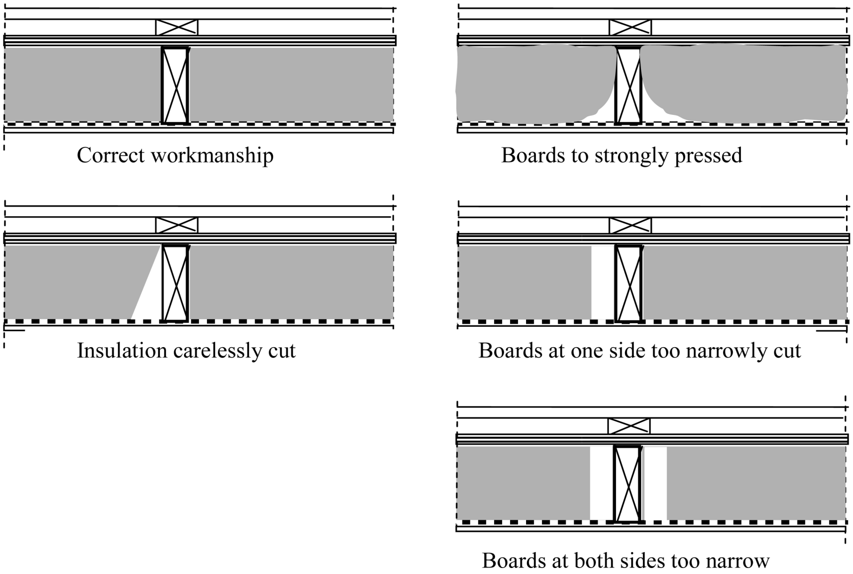


Figure 1.8. Typical workmanship inaccuracies.

1.2.2.3 Transient response

On a daily basis, timber-framed outer walls have an admittance way below 3.9 W/(m$^2\cdot$K) (for a surface film coefficient indoors of 7.8 W/(m$^2\cdot$K)), while the dynamic thermal resistance hardly differs from the steady state thermal resistance and temperature damping does not even approach a value 15. Better thermal insulation hardly changes things, see Table 1.7.

Table 1.7. Temperature damping, dynamic thermal resistance, and admittance (1-day period).

Wall, brick veneer as outside finish	Temperature damping + faze –, h		Dynamic thermal resistance + faze m$^2\cdot$K/W, h		Admittance + faze W/(m$^2\cdot$K), h	
4 cm MW, U_o = 0.47 W/(m$^2\cdot$K)	2.1	7.0	2.8	4.2	0.74	2.9
14 cm EPS, U_o = 0.21 W/(m$^2\cdot$K)	4.3	9.3	6.6	5.0	0.65	4.3

Through that, limited glass area, effective solar shading, and well-designed nighttime ventilation gain importance in moderate climates. Of course, an alternative is to combine a timber-framed envelope with heavy weight inside partitions and floors. To underline the difference, Figure 1.9 gives the fabric related room damping as function of window area for a room with a volume of 4 × 4 × 2.7 m^3, a 4 × 2.7 m^2 timber-framed outer wall, clear wall thermal transmittance of 0.16 W/(m$^2\cdot$K), timber framed partition walls and joisted floors and, for the same room but now with brick partitions and concrete floors. With massive inside partitions and floors, damping increases by a factor of 4.

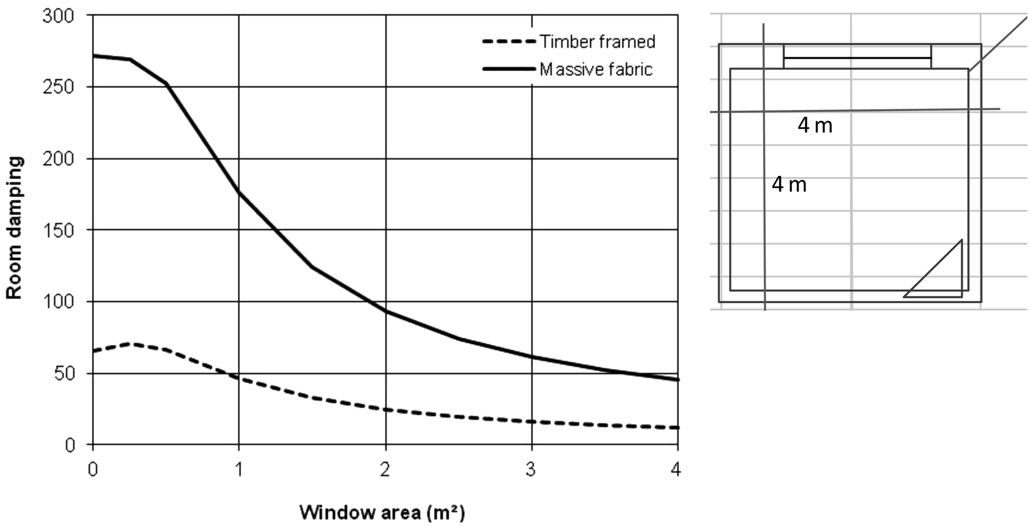


Figure 1.9. Fabric related room damping, integral timber framed versus outer wall only, in combination with massive partition walls and floors.

1.2.2.4 Moisture tolerance

Due to water sensitivity of the softwood used, timber-framed construction is inherently less moisture tolerant than massive construction. Above a moisture ratio of 20% kg/kg the risk to see mould colonizing the timber increases sharply whereas above 30% kg/kg fungal attack and bacterial rot become likely. To avoid problems the following requirements should be fulfilled:

1. Building moisture in studs, plates and joist must dry without damage
2. Once the construction is finished, rain should no longer seep in and humidify either the sheathing or the timber frame
3. Studs and plates should not suck water out of capillary porous materials they contact
4. Annually cumulating interstitial condensate is not allowed while a too high winter relative humidity lifting moisture ratio in the sheathing and frame beyond 20% kg/kg is excluded
5. Solar driven vapour flow giving moisture build-up in the insulation and moisture deposit against the air and vapour retarder or the inside lining should be avoided

Requirement 1

A vapour permeable outside finish facilitates fast drying of building moisture. Tests in the moderate, humid climate of Newfoundland, Canada, on eight walls proved building paper with low diffusion resistance is quite effective. All walls had a PE air and vapour retarder at their inside. Wall 1 and 2 were insulated with 14 cm mineral wool. Their frame was OSB sheathed and covered with building paper. Insulation in walls 3 to 6 was 8 cm mineral wool. For 3 and 4 the sheathing consisted of dense, 38 mm thick mineral wool boards covered with a vapour permeable spun-bonded foil. 5 and 6 had a 38 mm thick XPS sheathing, covered with the same spun-bonded foil. Wall 7 was insulated with 14 cm wet sprayed cellulose and

Table 1.8. Drying of timber framed walls (St John's, New Foundland).

Wall	R_1-value	µd sheathing + building paper	Building moisture	Moisture ratio after 1 year, % kg/kg			
				North		South	
	$m^2 \cdot K/W$	m	% kg/kg	U	D	U	D
1.	4.1	4.3	26–30	21	31	20	20
2.	4.3	4.3	26–30	25	35	18	20
3.	**3.8**	**0.01**	**26–30**	**12**	**15**	**12**	**16**
4.	**3.9**	**0.01**	**26–30**	**11**	**15**	**10**	**15**
5.	3.9	5.9	26–30	23	29	18	25
6.	4.1	5.9	26–30	20	27	15	18
7.	**3.9**	**4.3**	**26–30**	**45**	**76**	**68**	**118**
8.	3.7	3.9	26–30	10	17	14	15

U = up, D = down

finished with an OSB sheathing. Wall 8 finally got 127 mm EPS as insulation, which was covered with a vapour permeable foil. All walls had humid studs and plates with a building moisture ratio from 26 to 30% kg/kg. Table 1.8 gives the measured moisture ratio after one-year exposure.

Walls facing south dried faster than north facing ones. After 1 year, the studs of walls 3 and 4, the one with vapour permeable finish, are driest, with a moisture ratio largely below 20% kg/kg. Wall 8 lags behind somewhat. Wall 1, 2, 5, and 6 perform worse. To the north, they still show moisture ratios quite above 20% kg/kg, while to the south they drop just below. The situation in wall 7 is frankly dramatic. There, the high moisture content of the wet sprayed cellulose humidified the studs. Remarkably, due to air looping around and in the insulation moving air from the warm to the cold side at the top, all walls studs dry fastest there. On its way to the bottom, the air cools down causing water vapour picked up at the top to condense down on the sheathing.

Requirement 2

Draping the building paper so the overlaps allow functioning as second drainage plane, avoids rain from wetting the sheathing and timber frame. In addition, overhanging edges mask the delicate façade to roof transition while a backsplash zone in waterproof material above grade is not a redundant luxury with a wood siding or stucco outside finish.

Requirement 3

Requirement 3 determines how to solve the details above grade. In a humid climate, foundation walls and ground floor decks are best executed in a stony material on which the timber-framed walls are mounted. Between grade and lowest bottom plate one must respect a difference in level of at least 20 cm. Also, a continuous damp proof layer should separate the lowest bottom plate from the foundation walls or floor deck. The same damp proof layer is needed everywhere studs contact stony materials that can turn wet.

Requirement 4

Without a continuous air retarder, air-tightness of timber-framed outer walls remains defective. Even when correctly mounted, an air permeance below 10^{-5} kg/(m$^2 \cdot$ s $\cdot$ Pa) at 1 Pa air pressure difference is hardly realizable. As Figure 1.10 underlines, even at moderate air outflow, vapour resistance of the inside finish and building paper have a marginal impact on the amount of condensate deposited at and in the sheathing.

Not only do amounts of condensate vary with height, the worst situation occurs when the leaks at both sides of the insulation are far apart. Clearly, deducing vapour resistance requirements from a Glaser calculation does not work.

Figure 1.11 illustrates the effect of local leaks in the inside finish and the sheathing, coupled to air looping in and around the insulation.

Simulation with more complete models gave following guidance:

1. Construct the envelope as airtightly as possible. Mounting a continuous air barrier foil between thermal insulation and inside finish with a service cavity left is one possibility. An alternative is to air-tighten the inside finish providing perforation afterwards is excluded
2. Thermal insulation must completely fill the space between sheathing and air barrier
3. If 1 and 2 are fulfilled, one must still respect in moderate climates the relations in Table 1.9 between vapour resistance of the air/vapour retarder and vapour resistance of the building paper. For other climates, different relations hold. For example in hot, humid ones that need sensible and latent cooling, the outside finish should have enough vapour retarding quality to exclude high relative humidity and interstitial condensation at the backside of the inside lining.

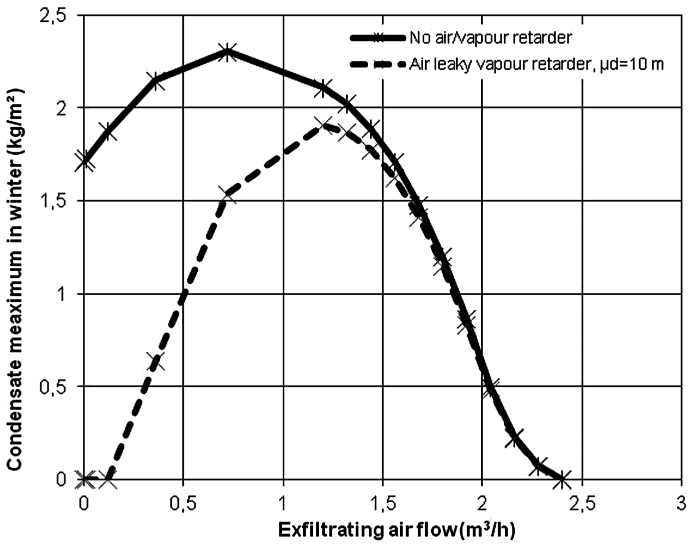


Figure 1.10. Timber-framed outer wall, mineral wool insulated, $U_o = 0.21$ W/(m$^2 \cdot$ K), diffusion thickness of the building paper 0.1 m, indoor climate class 3, moderate Uccle climate: impact of air outflow on maximum condensation deposit against and in the plywood sheathing at the end of the winter.

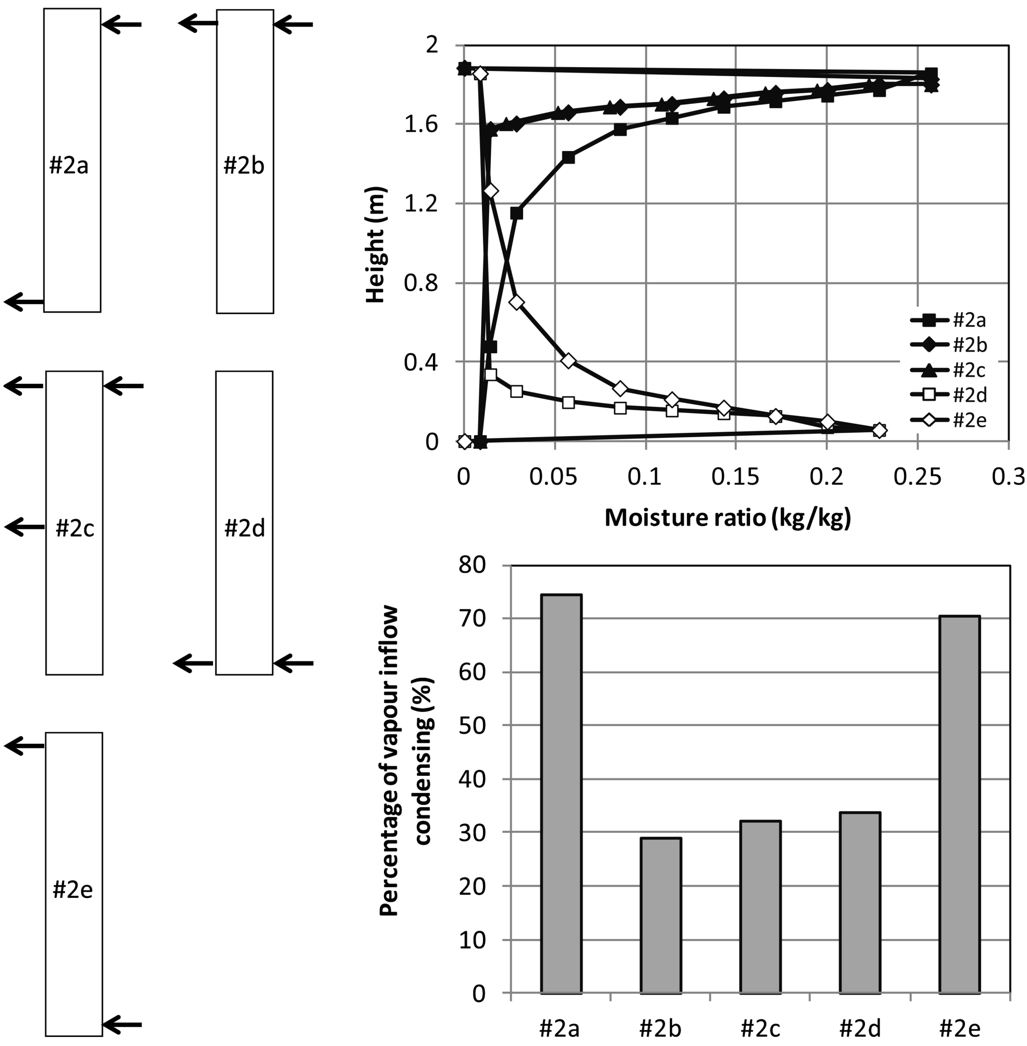


Figure 1.11. Timber-framed outer wall, mineral wool insulated, effect of air looping and air outflow on the distribution of condensate along the wall's height ($\theta_e = -10$ °C, $\theta_i = 20$ °C, $RH_i = 38\%$, outflow: 0.9 m^3/h, situation after 4 days).

Clearly, the requirements in indoor climate class 2 and 3 are far from severe. Or, timber framed outer walls in that type of buildings do not demand excessive vapour tightness at their inside. Air-tightness is what matters.

Table 1.9. Timber framed outer walls, relation between the diffusion thickness of building paper and air/vapour retarder (Uccle moderate climate).

Indoor climate class	Building paper $[\mu d]_{eq}$	Air/vapour retarder $[\mu d]_{eq}$
1	No requirements	
2	$[\mu d]_{\text{air/vapour retarder}} \le 1.43$ m and $[\mu d]_{\text{building paper}} \le \dfrac{2.6\,[\mu d]_{\text{air/vapour retarder}}}{2.04 - 1.43\,[\mu d]_{\text{air/vapour retarder}}}$	
3	$[\mu d]_{\text{air/vapour retarder}} \le 2.76$ m and $[\mu d]_{\text{building paper}} \le \dfrac{5\,[\mu d]_{\text{air/vapour retarder}}}{7.62 - 2.76\,[\mu d]_{\text{air/vapour retarder}}}$	
4, 5	Evaluate per case	

Requirement 5

Surely highly insulated timber framed outer walls finished with a brick veneer may suffer from solar driven vapour flow. An example are passive houses, where the outer walls consist of a timber framed inside leaf, lined inside with an air-tightened OSB sheathing and finished at the cavity side with a very vapour permeable wood fibre board (Figure 1.12). A 3 cm wide unvented cavity separates that inside leaf from a capillary active, 9 cm thick brick veneer, which at the rain side acts as rain buffer storing up to 14 litres per m^2 and more. During warmer weather after a rainy period, part of that moisture diffuses across the inside leaf to the inside where it humidifies the OSB. As the veneer stays at 100% relative humidity year round, relative humidity in the OSB inside lining fluctuates annually as shown in Figure 1.12.

Superimposed is a daily relative humidity oscillation at the OSB's cavity side with peaks over 90% in summer. In fact, temperature at the backside of a wet west over south-west to south looking brick veneer may pass 35 °C during warm summer days. Related vapour saturation pressure then reaches 5260 Pa, high enough to create a daily vapour flow to the inside, which further humidifies the OSB. Solar driven vapour flow activates the OSB's formaldehyde release during the summer months.

Practitioners have no clue of the problems solar driven vapour flow may cause. Avoidance however is simple, as it suffices using building paper that has a slightly higher diffusion resistance than the air/vapour retarding foil or sheathing inside. As Figure 1.13 underlines, such solution fits within the relations of Table 1.9. A less safe alternative consist of ventilating the cavity between brick veneer and timber-framed leaf.

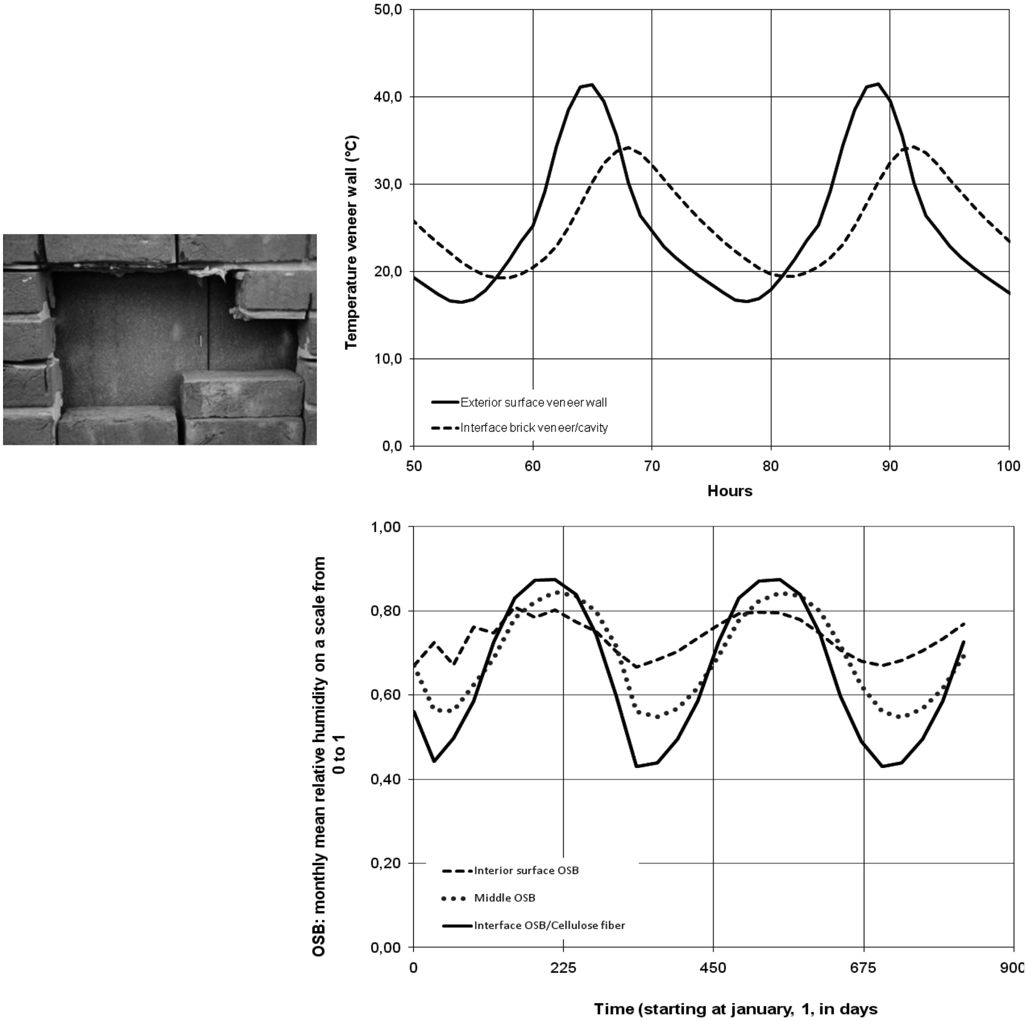


Figure 1.12. Passive house, solar driven vapour flow:
above temperature at the veneers backside, below relative humidity in the inside OSB air retarder.

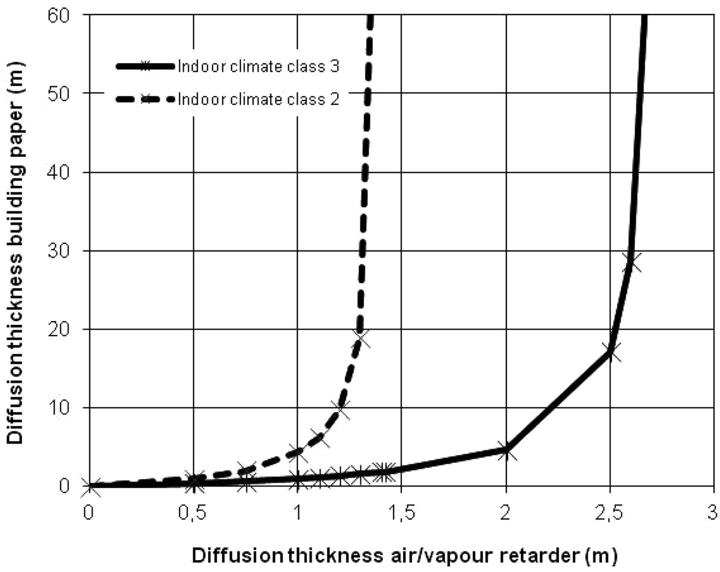


Figure 1.13. Timber-framed outer wall:
relation between the diffusion thickness of the air/vapour retarder and the building paper.

1.2.2.5 Thermal bridges

Limited thermal bridging is a clear advantage of timber-framed construction. Only when very low whole wall thermal transmittances are imposed, does one need engineered studs and alternative solutions for header plates, frame corners, window reveals and lintels, see Figure 1.14. Metal framed construction is a different story. As Table 1.5 showed, correct stud and plate shaping and the use of thermally insulating sheathing then becomes very important.

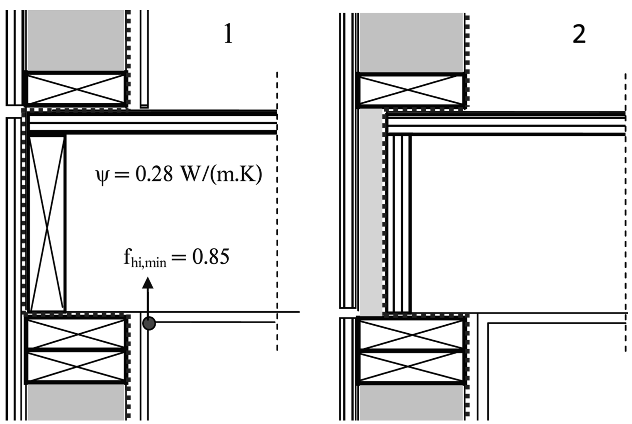


Figure 1.14. Timber-framed outer wall:
adapting header plate design to avoid thermal bridging.

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