Consequences for timber buildings of choices in national annexes to Eurocodes

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Background and purposes

The Danish authority responsible for building regulations wanted to know if the Danish NA to Eurocode 5

1. has higher requirements than in our neighbour countries
2. give rise to trade barriers

- Purpose 1 is investigated through comparing structural consequences of national choices. This involves also Eurocode 0 and 1
- Purpose 2 is investigated through a discussion of the complications national choices at various levels inflicts

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Eurocode parts used

Primary:

- EN 1990 (basis of design, safety)
- EN 1991-1-1,3,4 (self-weight, imposed, snow, wind)
- EN 1995-1-1 (timber)

Also:

- EN 1991-1-2 and EN 1995-1-2 (fire)
- EN 1998 (earthquake)

Study comprise NA's from:
Denmark, Sweden, Norway, Finland, Germany
+ recommended values in Eurocodes

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Comparison across borders

5 countries compared across borders at 7 places

Real loads assumed to be identical at those places (wind, snow and imposed)

Requirement index η used to quantify the differences in requirements

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Definition of requirement index η

Well suited to compare two sets of codes when using the *same material* when real exposure is identical

$$\eta_{A,B} = \frac{S_{A,d}}{R_{A,d}} \frac{R_{B,d}}{S_{B,d}}$$

where

- S_d is the design load on the structural component
- R_d is the load-carrying capacity of the component
- A and B represents the two codes to be compared

2nd (or 3rd) root of η is a measure of the amount of material needed

(Reliability index β requires strict statistical principles for estimating loads and safety factors)

General findings

Larger deviation of η from 1 due to few choices:

- Snow load and duration of snow load
- Partial factor on permanent load
- Imposed load (Live load)
- Load combination

Most national choices has minor effects

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Eurocode 5, major choices in NA's

		EC	DK	S	N	FI	D
Load duration class	Snow	S or M	S	M	S 40)	M	S 41)
	Wind	I or S	I	S	I 40)	I	S 42)
	q on floors	M	M	M	M	M	M
k_{mod} for timber, glulam, LVL and plywood (Service class 1 and 2)	Wind	1,1	1,1	0,9	1,1	1,1	1,0
	Snow	0,9	0,9	0,8	0,9	0,8	0,9
	Imposed	0,8	0,8	0,8	0,8	0,8	0,8
	Long	0,7	0,7	0,7	0,7	0,7	0,7
	Permanent	0,6	0,6	0,6	0,6	0,6	0,6
γ_M	Structural tim.	1,3	1,35	1,3	1,25	1,4 44)	1,3
	Glulam	1,25	1,3	1,25	1,15	1,2	1,3
	Plywood	1,2	1,3	1,2	1,15	1,25	1,3
	Connections	1,3	1,35	1,3	1,3	As timber	1,3 45)
	Tooth plate	1,25	1,35	1,25	1,25	1,25	1,25

40) N: In special cases M for snow and S for wind
41) D: S up to 1000 m, M above 1000 m
42) D: It is allowed to use k_{mod} = 1,0 for wind
44) FI: 1,25 for C35 and higher
45) D: 1,1 for laterally loaded connections (counteracts a change of characteristic capacity in NA)

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Eurocode 5, secondary choices in NA's

		EC	DK	S	N	FI	D
k_{cr}		0,67	1,00	46)	0,67 56)	0,67 47)	48)
Tapered beams, eq. 6.54 or 6.55		6.54	6.55	6.54	both	6.55 49)	6.54
Nail in end grain allowed		-	yes 50)	no	yes	yes	no
Bracing of compressed members 9.2.5	k_s	4	3	4	4	2 51)	4
	k_{f1}	50	80	50	50	50	50
	k_{f2}	80	100	80	80	80	80
	k_{f3}	30	50	30	30 52)	50	30
Vibration of floors 7.3.3 (2)	a, mm/kN	Recom.	2 53)	1,5	EC 54)	0,5 55)	EC
	b, m/Ns^2	relation	80	100	rec.		rec.

46) S: Rules equal to $f_{v,k}$ = 3 MPa for struct. timber and glulam. Exposed to rain or sun k_{cr} = 0,67
47) FI: 1,0 if moisture transfer is prevented or permanent high MC.
48) D: for C24-30. Rules equal to $f_{v,k}$ = 2 MPa for struct. timber and 2,5 MPa for glulam. Can be increased by 30 % from 1,5 m from beam ends.
49) FI: if moisture transfer is prevented, otherwise 6.54
50) DK: smooth nails not allowed in end grain
51) FI: k_s larger if more than 2 bays but < 4
52) N: for glulam k_{f3} = 50
53) DK: or for span < 6 m simple deflection < 1,7 mm/kN
54) N: or for span < 4,5 m simple deflection < 0,9 mm/kN (0,6 for high stiffness)
55) FI: Alternative method given regarding total deformation of floor
56) N: 0,8 for gluelam

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Background for differences

Scientific disagreements or National traditions?

- Duration of load – scientific disagreement
- Partial factor – scientific disagreement
- Shear strength, k_{cr} – lack of knowledge => traditions
- Bracing of compressed members – lack of knowledge (?)
- Deflections and vibrations of floors – tradition (and material specific requirements)

Fasteners and connections

- Eurocode 5 incomplete for modern fasteners
- ETA- or CUAP-approvals widely used
- National rules hidden in directions etc.
- Germany has rewritten section on lateral load
  - simplify calculation
  - covers more subjects
  - still incomplete

=> Impossible to determine requirement index η for fasteners and connections

! Improvement of fastener section in revised Eurocode 5 most important, also to ensure designers confidence

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Eurocode 0, Load combinations

- National choice between (6.10) or (6.10a) & (6.10b)

$$Q_d = \gamma_G G_k + \gamma_{Q,1} Q_{k,1} + \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \qquad (6.10)$$

$$Q_d = \mathrm{Max} \begin{cases} \gamma_G G_k + \gamma_{Q,1} \psi_{0,i} Q_{k,1} + \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10a) \\ \xi \gamma_G G_k + \gamma_{Q,1} Q_{k,1} + \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10b) \end{cases}$$

- Germany uses (6.10)
- Nordic countries (6.10a) and (6.10b)
- In Denmark and Finland (6.10a) used without variable load (so never decisive for timber)

=> 3 different methods

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Eurocode 0, partial factors etc. on loads

			EC	DK	S	N	FI	D
Load combination factors ψ_0		Load cat A	0,7	0,5	0,7	0,7	0,7	0,7
		Load cat B	0,7	0,6	0,7	0,7	0,7	0,7
		Snow	0,5 [1]	0,3 [4]	0,7 [2]	0,7 [3]	0,7	0,5 [1,5]
		Wind	0,6	0,3	0,3	0,6 [3]	0,6	0,6
Partial factors in Set B, Table A1.2(B)	Eq. 6.10b or 6.10	$\gamma_{G,sup}$	1,15 [6]	1,00	1,20 [7]	1,20 [7]	1,15	1,35
		$\gamma_{G,inf}$	1,00	0,90	1,00	1,00	0,90	1,00
		γ_Q	1,50	1,50	1,50	1,50	1,50	1,50
	Eq. 6.10a	$\gamma_{G,sup}$	1,35	1,20	1,35	1,35	1,35	-
		$\gamma_{G,inf}$	1,00	1,00	1,00	1,00	0,90	-
		γ_Q	1,50	0,00	1,50	1,50	0,00	-
Consequence class K_{FI}		CC1	0,90	0,90 [9]	0,83 [9]	1,00 [10]	0,90 [9]	0,90
		CC2	1,00	1,00	0,91 [11]	1,00	1,00	1,00
		CC3	1,10	1,10	1,00	1,00	1,10	1,10

1) EC+D: 0,5 but 0,7 in all N, S, FI and in other countries if altitude > 1000m
2) S: 0,6 for $s_k < 2$ kN/m^2, 0,8 for $s_k \geq 3$ kN/m^2
3) N: Modification by local authorities possible
4) DK: No snow when wind is leading action
5) D: For altitude < 1000 m wind and snow need not to be combined if both are accompanying actions. In wind zone III + IV no snow when wind is leading action
6) EC: $\xi \gamma_{G,sup} = 0{,}85 \cdot 1{,}35 = 1{,}15$
7) N+S: $\xi \gamma_{G,sup} = 0{,}89 \cdot 1{,}35 = 1{,}20$
9) DK+S+FI+D: CC1 for main structure only for non-occupied buildings
10) N: Requirements to inspection increases with CC. Single family and terraced houses in CC1
11) S: Called γ_d and referring to safety classes, but used as K_{FI}

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Eurocode 1-1-1, imposed loads

		EC	DK	S	N	FI	D
Imposed load	Load cat A	2,0	1,5	2,0	2,0	2,0	1,5 [1)]
q, kN/m²	Load cat B	3,0	2,5	2,5	3,0	2,5	2,0
Load reduction	A_0 m²	10	-	10	15	10	10
factors for floor	α_A A=25 m²	0,90 [6)]	1,00	0,90	1,00 [7)]	0,90 [8)]	0,90 [9)]
area A and no	α_A A=40 m²	0,75	1,00	0,75	0,88	0,80	0,75
of storeys n	α_n n=2	1,00 [10)]	0,75	1,00	1,00	1,00	1,00 [9)]
	α_n n=4	0,85	0,63	0,85	0,85	0,85	0,85
Distributed load	1 kN/m	0,5	0,5 [11)]	0,5	0,5	0,3 [12)]	0,8
from partition	2 kN/m	0,8	0,8	0,8	0,8	0,8	0,8
walls, kN/m²	3 kN/m	1,2	1,2	1,2	1,2	1,2	0,8

1) D: Provided adequate ability for transverse distribution of load, otherwise 2,0 kN/m²
(1,5 kN/m2 is always used for supporting structures).
6) EC: To be used for floors, roofs and beams
7) N: Can also be used for floors, roofs and beams instead of α_n. Guidance on determining A given.
8) FI: Restrictions apply to some types of floors
9) D: Eq for α_A and α_n rewritten. Guidance on determining A given.
10) To be used for walls and columns
11) DK: q = area weight of wall, min 0,5 kN/m²
12) FI: 0,3 kN/m² is used for light weight walls, not in NA

- No reasons for real loads to be very different

Eurocode 1-1-3, snow

- Ground now load jump sometimes over boarders
- Extreme load or extreme drifting not used in any country
- Snow accumulation on roofs supplemented or changed in several countries – not taken into account here
- Rules for accumulation needs improvement!

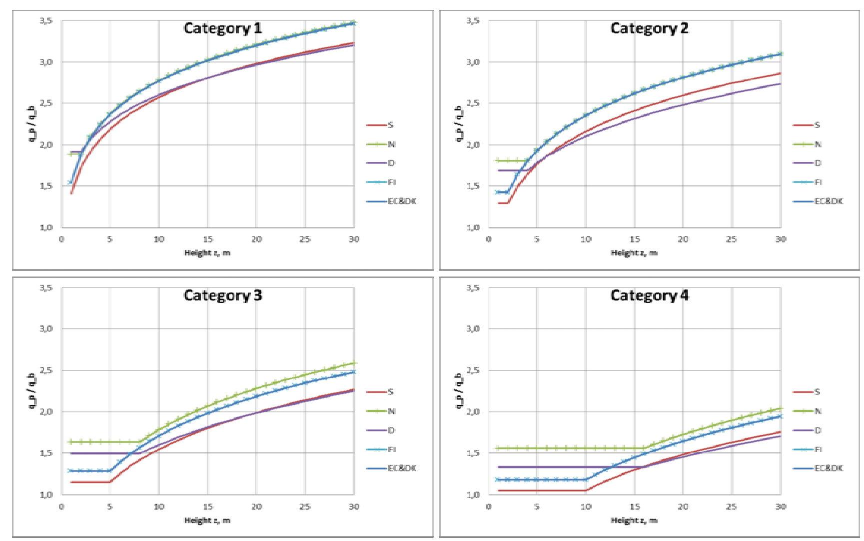
Eurocode 1-1-4, wind

		EC	DK	S	N	FI	D
Basic wind speed, m/s	$v_{b,min}$	-	24	21	22	21	22,5
	$v_{b,max}$	-	27	26	31	21	30
Deviations from EC for peak pressure				34)	35)	36)	37)
Structural factor from Annex B or C		B	C	- [38)]	B or C	B	- [39)]

34) S: Peak factor (1+6 I_v) instead of (1+7 I_v) in (4.8)
35) N: z_{min} higher than in Table 4.1; additional information given to 4.3.3 orography
36) FI: In category 0 is k_r increased to 0,18
37) D: Major parts rewritten
38) S: Method, different from both Annex B and C, given in NA.
39) D: Method in Annex B used, but major parts of 6.1 are rewritten.

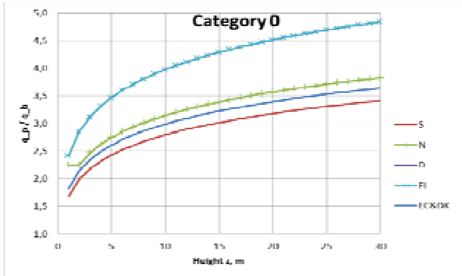
- Usage of terrain category different – redefined in Germany
- Correction for topography (orography) used differently

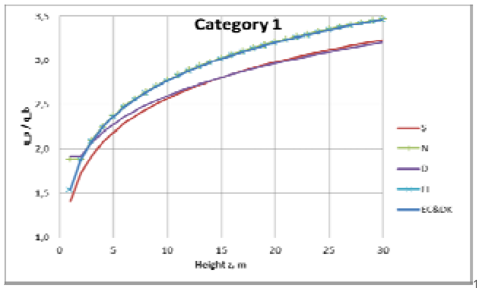
Wind load for terrain category



Wind load for terrain category 0

- Not used in DK and D
- Enlarged in FI





Wind and snow at comparable places

Place		v_b, m/s	s_k, kN/m^2
1. Denmark-Sweden across Øresund			
Copenhagen	DK	24	1,0
Malmö	S	26	1,0
2. Denmark-Germany across the border, east			
Padborg	DK	24	1,0
Flensburg	D	27,5	0,85
3. Denmark-Germany across the border, west			
Tønder	DK	25,3	1,0
Süderlügum	D	30	0,85
4. Sweden-Norway across Svinesund			
Svinesund (Strömstad)	S	24	2,0
Halden	N	24	3,0
5. Sweden-Norway, east of Oslo			
Eda (Charlottenberg)	S	23	3,0
Eidsskog (Hedmark)	N	22	3,5
6. Sweden-Finland, northern end of Bothnia Gulf			
Haparanda	S	22	3,0
Tomio	FI	21	3,0
7. Sweden-Norway-Finland at 3 country cross			
Kiruna	S	23	3,0
Storfjord, Troms	N	24	9,5
Enontekiö	FI	21	3,5

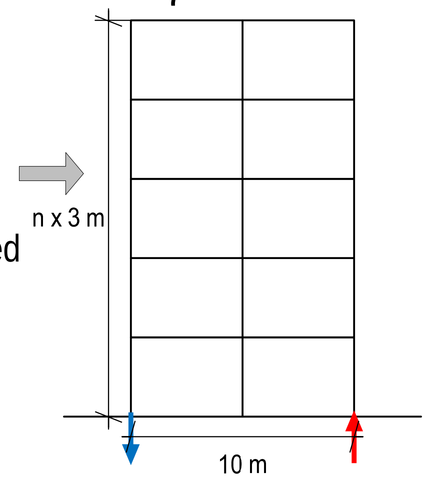
Examples of requirement index η

Building geometry considered:

- 2 or 4 storeys
- Housing (cat. A), CC2 or Offices (cat. B), CC3

Building components considered

- Roof beam
- Floor beam
- Wall, leeward facade
- Wall, windward facade



Floor beams, CC2, α_A = 1

	g_k, kN/m^2	EC	DK	S	N	FI	D
Load category A	0,5	1,21	1,00	1,11	1,18	1,31	1,12
(housing)	1,0	1,20	1,00	1,10	1,17	1,29	1,14
	2,0	1,18	1,00	1,09	1,15	1,27	1,17
Load category B	0,5	1,14	1,00	0,90	1,10	1,06	0,92
(offices)	1,0	1,13	1,00	0,91	1,10	1,07	0,95
	2,0	1,13	1,00	0,94	1,10	1,09	1,01

- Little influence of self-weight (Germany uses eq. (6.10))
- High value for Finland due to high partial factor on C18
- Difference between cat. A and cat. B due to
  - ratio between imposed load in cat. A and B
  - K_{FI} =1 in CC3 in Norway

Roof beams, CC2

Countries	Location	EC	DK	S	N	FI	D
Denmark-Sweden	1. Across Øresund	1,03	1,00	1,08			
Denmark-Germany	2. Across border, east	1,03	1,00				1,04
Denmark-Germany	3. Across border, west	1,03	1,00				1,04
Sweden-Norway	4. Across Svinesund	1,08		1,00	1,25		
Sweden-Norway	5. East of Oslo	1,09		1,00	1,21		
Sweden-Finland	6. Bothnia Gulf	1,09		1,00		1,17	
Sweden - Norway - Finland	7. 3 country cross	1,09		1,00	2,47	1,32	
All countries	Snow for Copenhagen	1,03	1,00	1,08	1,01	1,25	1,12

- High snow load in Norway, especially at location 7
- Snow is Medium duration in Sweden and Finland
- Finnish value due to high partial factor on struct. timber

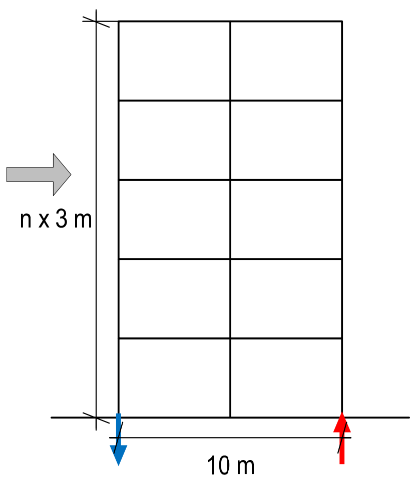
Leeward façade, 4-storeys, housing, CC2

Countries	Location	EC	DK	S	N	FI	D
Denmark-Sweden	1. Across Øresund	1,34	1,00	1,34			
Denmark-Germany	2. Across border, east	1,34	1,00				1,34
Denmark-Germany	3. Across border, west	1,33	1,00				1,46
Sweden-Norway	4. Across Svinesund	1,10		1,00	0,99		
Sweden-Norway	5. East of Oslo	1,10		1,00	0,98		
Sweden-Finland	6. Bothnia Gulf	1,07		1,00		1,14	
Sweden - Norway - Finland	7. 3 country cross	1,08		1,00	1,27	1,17	
All countries	Snow for Copenhagen	1,34	1,00	1,29	1,33	1,52	1,34

- Imposed load is leading action in most cases
- Wind is leading at location 3 on German side
- Snow is leading at location 7 on Norwegian side
- Denmark low due to low load reduction factors α_n and ψ_0
- 2-storeys or office-use and CC3 give similar results

Windward facade

- Anchoring needed for wind load in many cases
- Needed capacity of anchor very different due to choice of partial factors
- Highest requirements in Denmark and Finland
- Requirement index not η suitable because sign can be different



Fire (Eurocode 1-1-2 and 5-1-2)

- Eurocodes covers load-carrying capacity (R) and integrity and insulation (EI) for two scenarios:
  - Standard fire
  - Natural fire
- For Standard fire NA's are not very different
- For Natural fire NA's have all sorts of national deviations and differences
- In both cases Building Regulations in all countries give supplementary requirements and alternative methods

=> Impossible to determine requirement index η for fire

Earthquake (Eurocode 8)

- Only Norway and Germany has a NA (German only for southern regions)
- Denmark has a minimum horizontal static load, depending on the vertical load

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Discussion and conclusions 1

'All countries', wind and snow for Copenhagen:

Example	EC	DK	S	N	FI	D
Floor beam, Housing	1,20	1,00	1,10	1,17	1,29	1,14
Floor beam, Office-use	1,13	1,00	0,91	1,10	1,07	0,95
Roof beam	1,03	1,00	1,08	1,01	1,25	1,12
4-storey, Housing, CC2	1,34	1,00	1,29	1,33	1,52	1,34
4-storey, Office-use, CC3	1,27	1,00	1,09	1,13	1,28	1,14
2-storey, Housing, CC2	1,17	1,00	1,20	1,16	1,42	1,19
Mean index value for examples	1,19	1,00	1,11	1,15	1,31	1,15

- Load-carrying capacity low in Finland for structural timber
- Duration of snow (and wind) load
- Differences in imposed loads
- Differences in load combination (eq. 6.10, γ_M, ψ_0, α_A)
- (High Norwegian snow load not reflected here)

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Discussion and conclusions 2

- Most national choices has minor effect
- Complicated and 'illegal' rules in various countries NA's tends to regard the same subjects, e.g. k_{cr} and deflections
- Pin-points where Eurocodes are weak
- Differences can be due to
  - traditions
  - scientific disagreement
- National fire rules are the most important trade barrier
- Free trade requires that national requirements are given in terms of the same performances in all countries
- Major effects of NA's could be obtained with much fewer national choices and only on loads and load combinations

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