Zero Emission Building Envelopes - Comparison of Different Wall Constructions in a Life Cycle Perspective

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Background

- This work is part of the research program *Robust Envelope Construction Details for Buildings of the 21st Century* (ROBUST)
- There is a large potential for energy efficiency in buildings. In this context, insulation of the building envelope is a major contributor, both regarding energy efficiency and cost.
- When only energy use during operation of the building is considered, it will always be beneficial to increase the amount of insulation. However, when greenhouse gas (GHG) emissions during the life cycle is the evaluation criteria, the increased use of materials will at some stage equalize the benefits of reduced energy use during operation.

Objective

- This work presents a case study, where the effect of changing the insulation thickness of a wall is evaluated regarding GHG-emissions during the life cycle.
- The wall is a typical wood frame wall with glass wool, which is located in a house which fulfils the Norwegian energy regulations from 2010.
- The house is assumed to be located in Trondheim, Norway.
- The effect of changing the emission factor for the energy source has also been evaluated.
- The main question is: **Is there an optimum insulation thickness, and how do the emission factors influence the results?**

Description of house

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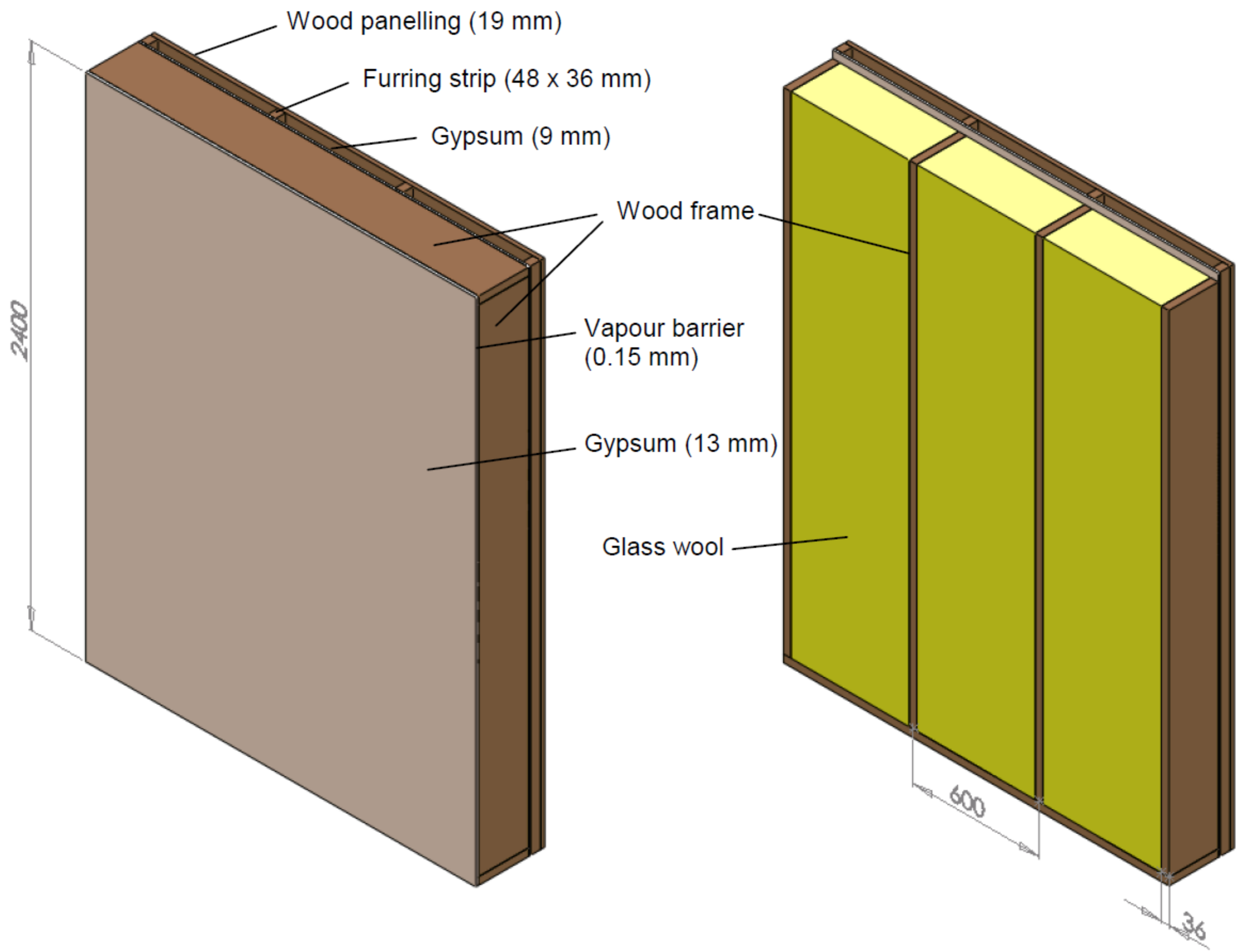
Dimensions (internal)	
	Length x Width: 10 m x 8 m
	Height: 5 m (2 floors)
	Heated floor area: A_{BRA} = 160 m²
	Heated air volume: V = 384 m³
External walls	
	Internal area including windows and door: A_{wall} = 180 m²
	Internal area excluding windows and door: $A_{wall\ net}$ = 148 m²
	Thermal transmittance: U_{wall} = 0.087 - 0.652 W/(m²K), depending on insulation thickness
Windows and door	
	Total area of windows and door: A_{wd} = 32 m² (A_{wd}/A_{BRA} = 20 %)
	Thermal transmittance of windows and door: U_{wd} = 1.2 W/(m²K)
Roof	
	Internal area: A_{roof} = 80 m²
	Thermal transmittance: U_{roof} = 0.13 W/(m²K)
Floor	
	Internal area: A_{floor} = 80 m²
	Thermal transmittance: U_{floor} = 0.15 W/(m²K)
Thermal bridges	
	Normalized thermal bridge value: ψ'' = 0,03 W/(m^2_{BRA}K)

Description of house

Air tightness	
	Air changes at 50 Pa: $n_{50} = 2.5\ h^{-1}$
Ventilation system	
	CAV ventilation
	Heat exchanger efficiency: $\gamma_{he} = 80\ \%$
	Ventilation rate: $V_V = 192\ m^3/\ h$
	Specific Fan Power: SFP = 2.5 kW/(m³s)
Heating and cooling	
	Electrical heating system
	Maximum effect for heating (including heating of ventilation air): $P_h = 10400$ W
	Heating efficiency: $\gamma_h = 100\ \%$
	No cooling
Internal loads	
	Lighting during operational hours (16/7/52): $P_l = 312$ W (312 W heat gain)
	Technical equipment during operational hours (16/7/52): $P_t = 480$ W (288 W heat gain)
	Domestic hot water: $P_{dhw} = 544$ W (0 W heat gain)
	Heat gain due to people: 240 W

Description of wall



Methodology

The reduction of GHG-emissions, related to reduced heating demand, when the insulation thickness of the wall is increased with one unit:

$$\Delta GHG(t_m)_{Operation} = \frac{(E_{t1} - E_{t2})KT}{(t_2 - t_1)A_{wall\ net}} \tag{1}$$

The increase of GHG-emissions, related to increased use of materials, when the insulation thickness of the wall is increased with one unit:

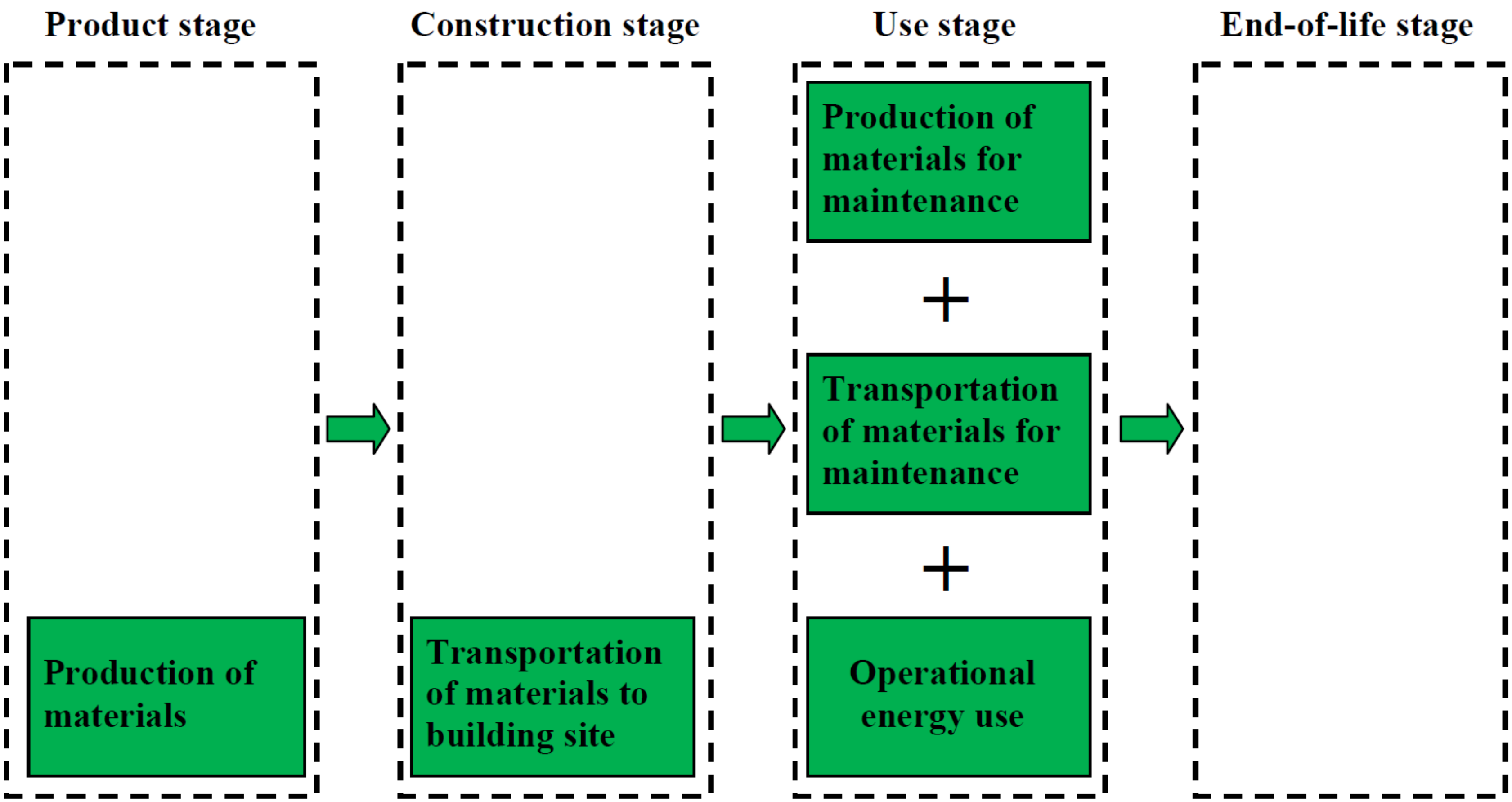
$$\Delta GHG(t_m)_{Materials} = \frac{GHG_{Materials\ t2} - GHG_{Materials\ t1}}{(t_2 - t_1)A_{wall\ net}} \tag{2}$$

The optimum point of reduced heating demand versus increased use of materials:

$$\Delta GHG(t_m)_{Operation} = \Delta GHG(t_m)_{Materials} \tag{3}$$

LCA – System boundaries

In this simplified life cycle assessment, only the following processes were included:



LCA – Production of materials

- Emission data for production of the materials was taken from Klimagassregnskap.no.
- The electricity specific part of the emissions related to production of the materials can be adjusted according to a user specified emission factor for electricity.
- Since there is no official emission factor for electricity from the Norwegian grid, and there are different arguments for which factor to use, the analyses have been carried out with 0.010, 0.050, 0.200, 0.400 and 1.000 kg CO_2 eq/kWh.

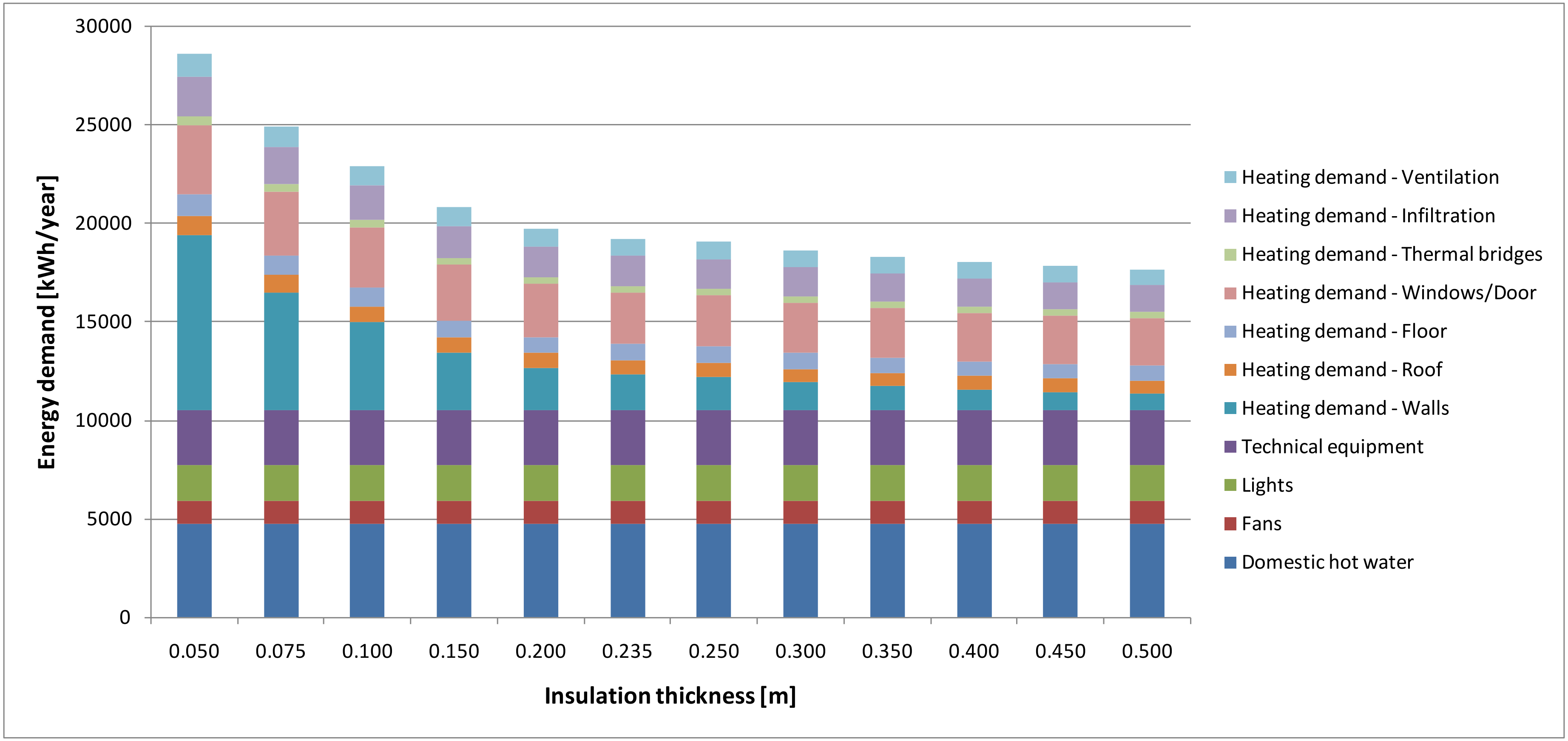
LCA – Transportation

The emission factor for transportation was taken from Klimagassregnskap.no.

The emissions per m^2 wall are calculated on basis of the following assumptions:

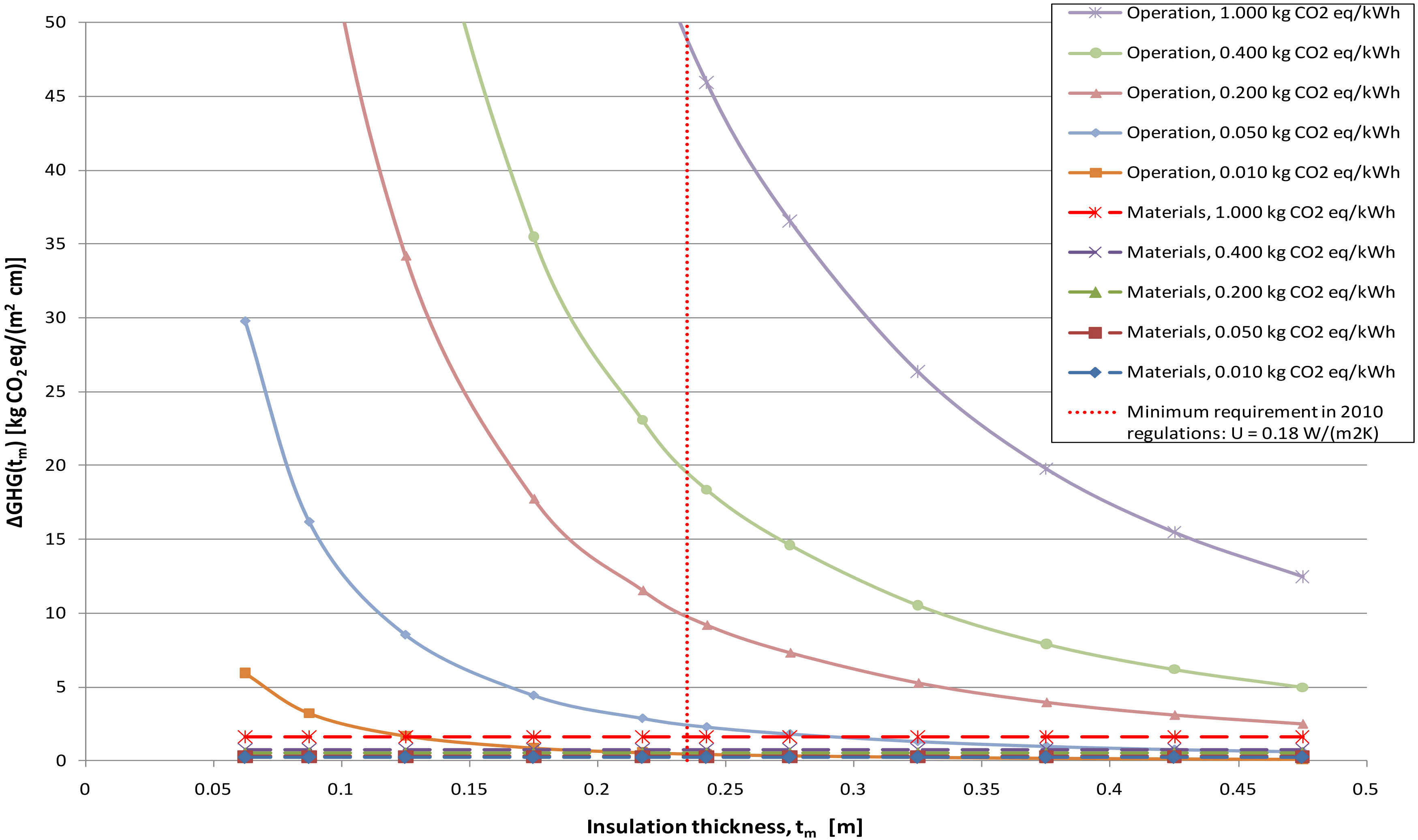
1. The travel distance from the manufacturer to the building site is 1000 km.
2. The maximum load capacity is 30000 kg for all the materials except the glass wool.
3. The maximum load capacity is 37 pallets with 3.7 m^3 glass wool per pallet.

LCA - Energy demand and emission factors

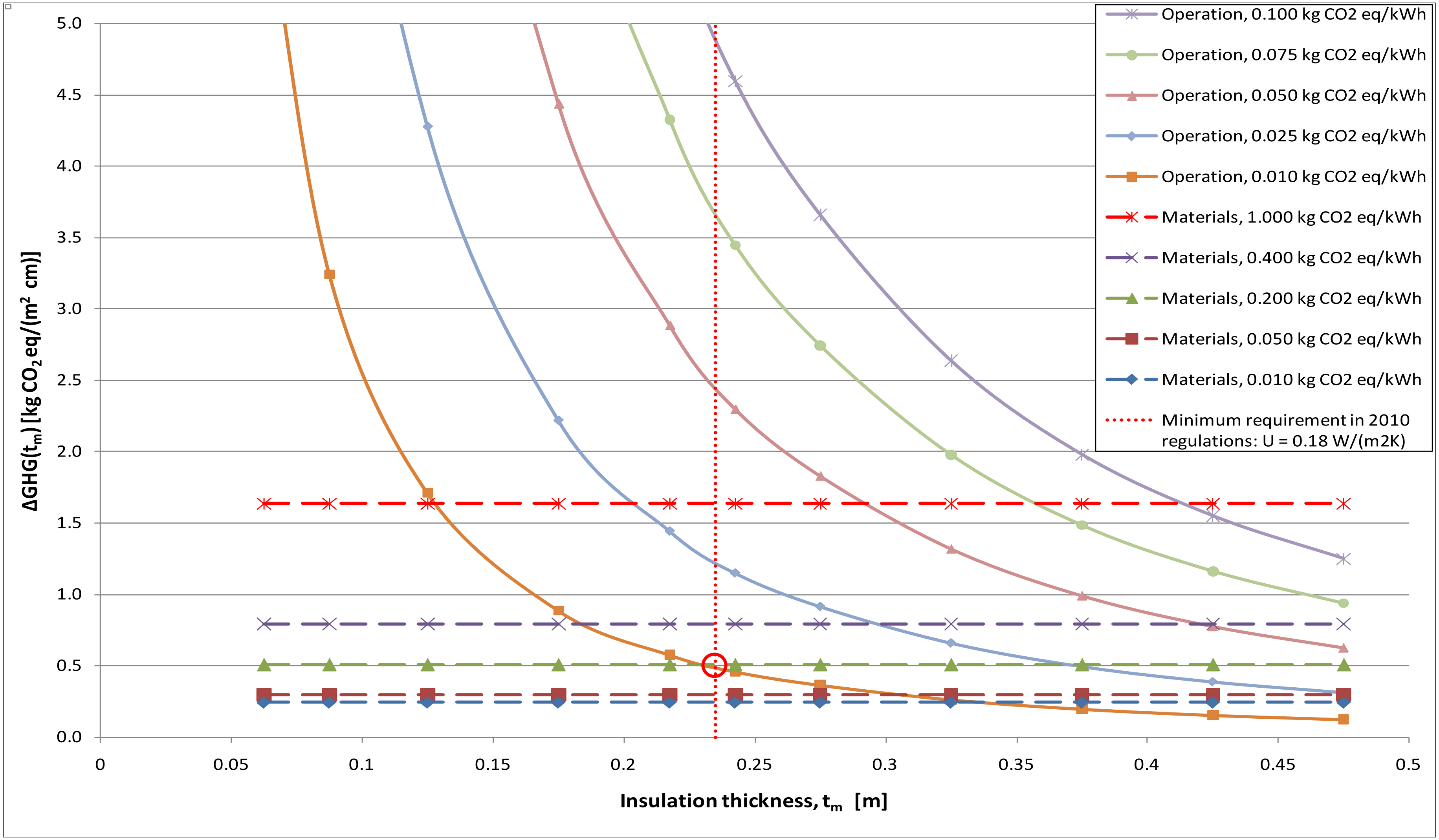


- Emission factors: 0.010, 0.025, 0.050, 0.075, 0.100, 0.200, 0.400 and 1.000 kg CO_2 eq/kWh.

Results


ΔGHG(t_m) [kg CO_2 eq/(m^2 cm)]
50
45
40
35
30
25
20
15
10
5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Insulation thickness, t_m [m]
Operation, 1.000 kg CO2 eq/kWh
Operation, 0.400 kg CO2 eq/kWh
Operation, 0.200 kg CO2 eq/kWh
Operation, 0.050 kg CO2 eq/kWh
Operation, 0.010 kg CO2 eq/kWh
Materials, 1.000 kg CO2 eq/kWh
Materials, 0.400 kg CO2 eq/kWh
Materials, 0.200 kg CO2 eq/kWh
Materials, 0.050 kg CO2 eq/kWh
Materials, 0.010 kg CO2 eq/kWh
Minimum requirement in 2010 regulations: U = 0.18 W/(m2K)

Results



5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ΔGHG(t_m) [kg CO2 eq/(m2 cm)]
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Insulation thickness, t_m [m]
Operation, 0.100 kg CO2 eq/kWh
Operation, 0.075 kg CO2 eq/kWh
Operation, 0.050 kg CO2 eq/kWh
Operation, 0.025 kg CO2 eq/kWh
Operation, 0.010 kg CO2 eq/kWh
Materials, 1.000 kg CO2 eq/kWh
Materials, 0.400 kg CO2 eq/kWh
Materials, 0.200 kg CO2 eq/kWh
Materials, 0.050 kg CO2 eq/kWh
Materials, 0.010 kg CO2 eq/kWh
Minimum requirement in 2010 regulations: U = 0.18 W/(m2K)

Conclusions

- The energy sources and the corresponding emission factors are of great importance when the optimum insulation thickness is determined on basis of GHG-emissions (CO_2-equivalents) during the life cycle.
- Increased insulation thickness is always beneficial as long as the emission factor for the energy supply to the building is above 0.200 kg CO_2 eq/kWh.
- There is an optimum insulation thickness between 0.050 m and 0.500 m when the emission factor for the energy supply to the building is below 0.100 kg CO_2 eq/kWh. The specific optimum insulation thickness depends upon the combination of emission factors.

Recommendations for further work

- Different combinations of wall structures and energy supply systems should be investigated.
- The effect of cooling demand should be investigated.

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