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

Thomas Haavi $^{1,2,*}$ and Arild Gustavsen $^1$

$^1$ Department of Architectural Design, History and Technology, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway.

$^2$ Department of Materials and Structures, SINTEF Building and Infrastructure, NO-7465 Trondheim, Norway.

* Corresponding author, Phone +47 98230442, Thomas.Haavi@ntnu.no

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

## Dimensions (internal)
- Length x Width: 10 m x 8 m
- Height: 5 m (2 floors)
- Heated floor area: $A_{BRA} = 160 \text{ m}^2$
- Heated air volume: $V = 384 \text{ m}^3$

## External walls
- Internal area including windows and door: $A_{wall} = 180 \text{ m}^2$
- Internal area excluding windows and door: $A_{wall_{net}} = 148 \text{ m}^2$
- Thermal transmittance: $U_{wall} = 0.087 - 0.652 \text{ W/(m}^2\text{K)}$, depending on insulation thickness

## Windows and door
- Total area of windows and door: $A_{wd} = 32 \text{ m}^2$ ($A_{wd}/A_{BRA} = 20 \%$)
- Thermal transmittance of windows and door: $U_{wd} = 1.2 \text{ W/(m}^2\text{K)}$

## Roof
- Internal area: $A_{roof} = 80 \text{ m}^2$
- Thermal transmittance: $U_{roof} = 0.13 \text{ W/(m}^2\text{K)}$

## Floor
- Internal area: $A_{floor} = 80 \text{ m}^2$
- Thermal transmittance: $U_{floor} = 0.15 \text{ W/(m}^2\text{K)}$

## Thermal bridges
- Normalized thermal bridge value: $\psi'' = 0.03 \text{ W/(m}^2\text{BRA} \text{K)}$
Description of house

Air tightness
Air changes at 50 Pa: $n_{50} = 2.5 \text{ h}^{-1}$

Ventilation system
CAV ventilation
Heat exchanger efficiency: $\gamma_{he} = 80 \%$
Ventilation rate: $V_V = 192 \text{ m}^3/\text{h}$
Specific Fan Power: $\text{SFP} = 2.5 \text{ kW/(m}^3\text{s)}$

Heating and cooling
Electrical heating system
Maximum effect for heating (including heating of ventilation air): $P_h = 10400 \text{ W}$
Heating efficiency: $\gamma_h = 100 \%$
No cooling

Internal loads
Lighting during operational hours (16/7/52): $P_l = 312 \text{ W}$ (312 W heat gain)
Technical equipment during operational hours (16/7/52): $P_t = 480 \text{ W}$ (288 W heat gain)
Domestic hot water: $P_{dhw} = 544 \text{ W}$ (0 W heat gain)
Heat gain due to people: 240 W
Description of wall

- Wood panelling (19 mm)
- Furring strip (48 x 36 mm)
- Gypsum (9 mm)
- Wood frame
- Vapour barrier (0.15 mm)
- Gypsum (13 mm)
- Glass wool
Methodology

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

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

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

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

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

$$\Delta GHG(t_m)_{Operation} = \Delta GHG(t_m)_{Materials} \quad (3)$$
LCA – System boundaries

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

1. Production of the materials which were used in the initial construction of the walls
2. Transportation of the materials from the manufacturer to the building site
3. Production of materials for maintenance
4. Transportation of materials for maintenance (from the manufacturer to the building)
5. Operational energy use

Item 1 to 4 is the basis for the calculation of $\Delta \text{GHG}_{\text{Materials}}$, while item 5 is the basis for the calculation of $\Delta \text{GHG}_{\text{Operation}}$. 
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 CO₂ eq/kWh.
LCA – Transportation

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

The emissions per m² 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 m³ 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 CO₂ eq/kWh.
Results

\[ \Delta \text{GHG} (t_m) = [\text{kg CO}_2 \text{ eq/(m}^2 \text{ cm)}] \]

Insulation thickness, \( t_m \) [m]

- Operation, 1.000 kg CO\(_2\) eq/kWh
- Operation, 0.400 kg CO\(_2\) eq/kWh
- Operation, 0.200 kg CO\(_2\) eq/kWh
- Operation, 0.050 kg CO\(_2\) eq/kWh
- Operation, 0.010 kg CO\(_2\) eq/kWh
- Materials, 1.000 kg CO\(_2\) eq/kWh
- Materials, 0.400 kg CO\(_2\) eq/kWh
- Materials, 0.200 kg CO\(_2\) eq/kWh
- Materials, 0.050 kg CO\(_2\) eq/kWh
- Materials, 0.010 kg CO\(_2\) eq/kWh

Minimum requirement in 2010 regulations: \( U = 0.18 \text{ W/(m2K)} \)
Results

\[ \Delta GHG(t_m) \text{ [kg CO}_2\text{ eq/(m}_2\text{ cm)}] \]

- Operation, 0.100 kg CO\text{2 eq/kWh}
- Operation, 0.075 kg CO\text{2 eq/kWh}
- Operation, 0.050 kg CO\text{2 eq/kWh}
- Operation, 0.025 kg CO\text{2 eq/kWh}
- Operation, 0.010 kg CO\text{2 eq/kWh}
- Materials, 1.000 kg CO\text{2 eq/kWh}
- Materials, 0.400 kg CO\text{2 eq/kWh}
- Materials, 0.200 kg CO\text{2 eq/kWh}
- Materials, 0.050 kg CO\text{2 eq/kWh}
- Materials, 0.010 kg CO\text{2 eq/kWh}

Minimum requirement in 2010 regulations: \( U = 0.18 \text{ W/(m2K)} \)
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 (CO₂-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 CO₂ 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 CO₂ 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.
References

- Klimakalkulatoren. 2010. Design of a household emissions calculator. www.klimakalkulatoren.no
- Ministry of local government and regional development (KRD). 2010. FOR 2010-03-26 nr 489: Regulations on technical requirements for construction (in Norwegian). KRD.