Natural Energy Efficiency and Sustainability (NEES)

Pilot Project: An ecological and sustainable Passive House 300 km south of the northern Arctic Circle

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1. Description of the Project

The challenge facing this project was to come up with a building design process that would allow first through third-year students at a trade school to build high-quality Passive House buildings in the far north with environmentally friendly, renewable construction materials. From the very beginning, the single-family homes were designed to implement local environmental goals. The vocational school aims to train its students to a very high level, which of course includes construction projects that already strive to meet future construction standards. The challenge of designing a Passive House building 300 km south of the Arctic Circle required a verified calculation tool; we chose the PHPP. Even at the beginning of the process, it was clear that the homes could not achieve the heating demand of < 15 kWh/(m_2a) called for in the international Passive House definition while also using renewable, zero-emission construction materials. The client therefore decided to plan for FEBY, a national Passive House certificate. Quality is defined based on a project-specific quality and environmental plan and on adaptation of other certification systems – in this case, the national Passive House certificate FEBY and the highest class (gold) of the national sustainability certificate MiljöByggnad. At a later point in the project, the international Passive House certificate for pilot projects also became a factor.

2. Contribution to Resource Efficiency

The project's environmental and quality plan includes the following topics:

- Non-toxic indoor climate with low thresholds for formaldehyde, VOCs, TVOCs, CO2, and radon – we need to build for people; otherwise, it doesn't make sense = strict limits on emissions in indoor air
- Highest possible resource and energy efficiency with maximum comfort and quality while also reducing CO2 emissions = international Passive House certification
- Renewable energy for residual energy demand = Nearly Zero-Energy Building
- Renewable, zero-emission construction materials with low embodied energy levels
- (LCA) External quality assurance (not typical in the Swedish construction process) on the construction site plus quality assurance based on Passive House and sustainability certification
- Materials and structures with long service lives, low maintenance expenses, easy to update and dismantle (LCC)
- Flexible floor plans, flexible and easily accessible building services equipment, nonloadbearing walls inside, accessible ventilation system
- Possibility of prefabricating building components for higher construction quality
- Good location, well connected to local transportation and commercial and public facilities

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- Use of existing infrastructure

3. Environment and Health

Non-toxic indoor climate with low thresholds for formaldehyde, VOCs, TVOCs, CO2, and radon – we need to build for people; otherwise, it doesn't make sense = strict limits on emissions in indoor air

Outside wall	0.065 W/(m²K)
Roof	0.055 W/(m²K)
Floor slab	0.085 W/(m²K)
Energy value for heating	18 kWh/(m²a)
Treated floor area – PHPP	146 m²
Treated floor area based on Swedish calculation standard A_{temp}	158 m²
Number of residents	5
Windows including glazing 0.5 W/(m²K)	0.68 with g= 51%
Ventilation with efficient heat recovery	94%
Residual energy demand	Mountain heat pump + floor heating
Electricity	Community wind energy project – 4 shares 1,000 kWh @ 700€

The electricity needed for heat, hot water, and other applications in the building amounts to 3,500 kWh/a.

4. Sustainability

In 2012, FEBY[1] certified the first three buildings according to the Swedish Passive House Standard. Because the heating demand is 18 kWh/(m2a), international Passive House certification is not possible. The Passive House Institute's suggestion of using insulation with a much lower lambda value was considered based on a simple calculation of cumulative primary energy consumption. Because the buildings strive for all Passive House quality criteria, were planned with the PHPP, and use only certified PH components of the highest quality, the project was nevertheless designated a "pilot project" in October 2013.

LCAs were conducted early on in the planning stage for a number of building envelope structures common in Sweden. We decided on a Passive House-quality building envelope with I-joists and cellulose insulation based on those calculations and the city council's environmental resolutions. The trade school approved of the decision to use I-joists because it fits in well with training goals. Thermal benefits and the factory's location only 50 km away were also viewed positively. Because each group of students, based on the year they began vocational school, should have "their own construction site," single-family homes had to be built instead of duplexes, which would have had a heating demand of 15kWh/(m2a). Much of the focus on potential thermal improvements was therefore placed on comparing the environmental effects of different kinds of insulation. Because CPEC is based on how much primary

energy is used, it is an ideal indicator of energy resource consumption. It also means that all different kinds of energy use included in cumulative energy consumption must be considered in relation to primary energy use. Using PUR/PIR insulation meant that insulation thickness in the building envelope could be reduced to 10 cm and a maximum heating demand of 15 kWh/(m2a) could be achieved. PIR/PUR insulation, which has a much lower thermal conductivity (λ), meant the project could earn standard Passive House certification, but it also entails much higher primary energy consumption for production, uses crude oil, and has a significantly higher GWP. A
simplified lifecycle assessment showed that a Passive House building insulated with recycled natural fibers would have a lower CPEC and GWP and, therefore, significant environmental benefits. PIR/PUR insulation would reduce the environmental footprint on the site by 3.6 m2, which was not taken into account when comparing ecological aspects of the various insulation materials.

Calculation of cumulative energy consumption	Pilot certificate	Passive House certificate
Insulation	Cellulose 039	Hard resol foam 022
U average – thermal envelope (W/(m^{2}K))	0.107	0.094
Treated floor area (m^2)	148	148
Heating demand (kWh/(m^{2}a))	17.8	15
PE heat (kWh/(m^{2}a)) from water/water geothermal pump, COP 3,8 , PE electricity = 2.9	13.6	11.5
Primary energy for heat per year (kWh/a)	2013	1702
Primary energy for heat over 50 years (kWh/50a)	100,650	85,100
Insulation volume (m^3)	205	165
Insulation density (kg)	54	40
Total weight of insulation (kg)	11,070	6,600
Primary energy – insulation (MJ/kg)	6.3	133
Primary energy – all insulation (MJ)	69,740	877,800
Primary energy – all insulation (kWh)	19,372	243,833
Total primary energy = (kWh/50 a) PE_{total} heating energy +PE_{total} insulation	120,022	328,933
CPEC (heating demand + insulation) (kWh/m^{2}a)	16.21	44.45
Additional primary energy demand for 15 kWh Passive House	+/- 0	+ 64 %
Global warming potential (GWP) calculation		
GWP insulation (kg $CO_{2\,equ}$/kg)	-0.88	5
Total weight of insulation (kg)	11,070	6,600
GWP all building insulation (kg $CO_{2\,equ}$)	-9,742	33,000
PE heat (kWh/(m^{2}a)) from water/water geothermal pump, COP 3,8 , PE electricity = 2.9	13.6	11.5
Primary energy for heat over 50 years (kWh/50a)	100,650	85,100
GWP EU power mix (kg $CO_{2\,equ}$/kWh)	0.68	0.68
GWP of heat pump for heating demand (kg $CO_{2\,equ}$/50 a)	68,442	57,868
GWP total for heat 50 a + insulation (kg $CO_{2\,equ}$)	58,700	90,868
GWP heating demand + insulation (kg $CO_{2\,equ}$/(m^{2}a)	7.9	12.3
	+/- 0	+ 35 %

5. Enterprise aspects

Constructing energy-efficient buildings was not the only project goal. City council resolutions stipulate that renewable construction materials must always be given preference over nonrenewable materials and that, starting in 2012, all educational facilities must be free of toxic substances. Because the construction sites for this project serve as "classrooms" for the trade students,

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these guidelines were kept in mind when drawing up the building concept and choosing construction materials. Maximum emissions in indoor air are therefore also defined in the project's quality and sustainability plan. For all of the buildings' lifecycle stages, there was a consistent effort to reduce the consumption of energy and resources and minimize effects on the ecosystem.

6. Scalability

In Sweden, vocational training is mostly provided at trade schools. The country does not yet offer any specific training for tradespeople to reliably construct the Nearly Zero-Energy Buildings (NZEB) to be implemented throughout the European Union in the future – nor has a definition specific to Sweden even been drawn up for the standard. At the moment, 145 students are learning about their trades while working on six buildings in various stages of construction. After 2.5 years of construction, the first houses are due to be completed in April 2014. The EU directive on Nearly Zero-Energy Buildings was passed in 2010. In 2011, we worked with the vocational school's president and project director to develop this training concept in order to ensure that there would be enough qualified tradespeople in the Umeå labor market in 2019 to be able to construct this kind of forward-looking building. We also hope that the buildings will serve as an example for other trade schools throughout the country and contribute to the discussion on which energy standard Nearly Zero-Energy Buildings in Sweden can and should strive for.

7. Conclusions

Even vocational students new to the trades can construct high-quality Passive House buildings if plans on the construction site are comprehensive and detailed enough. The number of detailed sketches needed was underestimated. We also realized that regular site visits were necessary, although they are not the norm in Sweden, where building owners tend to trust the construction companies' own quality assurance processes. A significant benefit is that the planning architect (the author of this paper) is involved in theoretical lessons for the students and therefore has the opportunity to explain the sustainability concept and, in particular, the airtightness concept, including all important quality assurance measures. Freestanding single-family homes are far from the most efficient residential solution in terms of resources, but they are possible even close to the Arctic Circle. The unfavorable compactness of this kind of house explains the high transmission losses through the building envelope. If it were a duplex, this construction concept would certainly earn standard Passive House certification, but the vocational school's training concept requires single-family homes to be built. We don't see a way for the current construction concept to be improved for this site, based on PH components available on the market today, except by using insulation with a lower thermal conductivity. As previously discussed, however, we rejected this solution based on a calculation of the cumulative energy consumption.

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