A Net ZEB case study – Experiences from freezing in ventilation heat exchanger and measured energy performance

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Abstract. Net Zero Energy Buildings constitute one measure to reduce energy use and increase use of energy from renewable sources. Hence, it is important share knowledge and experiences from completed projects. This case study show that it is possible to build Net Zero Energy Buildings with existing techniques. However, a common strategy to prevent or limit the build-up of ice and frost in ventilation heat exchangers, Supply fan shut off, were not suitable this project, since it is air tight buildings. After occurring problems in the first winter, ventilation pre-heater were installed to prevent the build-up of ice and frost. Thanks to placement of temperature sensor after the pre-heater, the increased energy use for pre-heater may be expected to be low, roughly 1 kWh/m^{2}a.

Keywords: Net ZEB, Energy use, Freezing, Ventilation.

1 Introduction

Buildings account for over 40 % of the primary energy use worldwide and 24 % of its greenhouse gas emissions [1]. The world's population is growing and also the need for buildings. Hence, reduction of energy use and increased use of energy from renewable sources are important measures for climate change mitigation.

Many studies identify a performance gap between predicted energy use and actual measured energy use once buildings are in user phase [2-10]. Hence, it is important that energy use in user phase is measured and verified to enable dissemination of knowledge. Especially in high performance buildings such as Net Zero Energy buildings (NetZEBs).

This study presents a Net ZEB neighbourhood in the south of Sweden with verified plus energy performance. The technical solutions used and measured energy performance is presented. Experiences from the user phase is shared, with focus on problems related to freezing in the ventilation heat exchanger.

2 The case study

The case study consists of seven one-storey terraced houses (three dwellings in each house), built in the southern part of Sweden, see Figure 1.

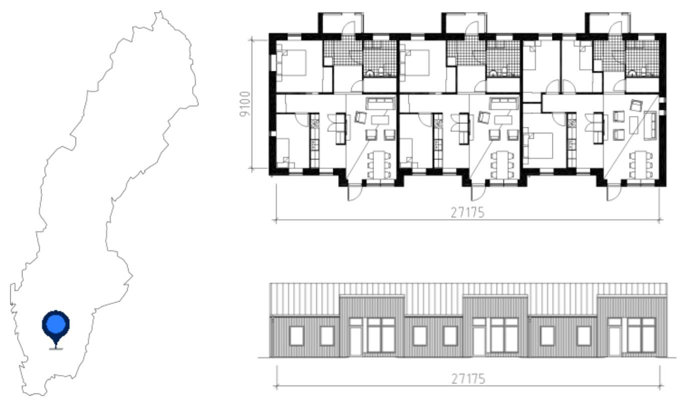

Fig. 1. Left: Location of case study in Sweden. Top right: Layout of terraced house. Bottom left: Facade facing south

The Net ZEB balance were reached in three steps:

1. Reduction of thermal losses by designing the buildings with an air tight and well insulated building envelope and using balanced mechanical ventilation with high heat recovery, heat recovery ventilation (HRV). The occupants has the possibility to increase the ventilation, manually or set point based. One HRV unit per dwelling.
2. Reduction of need for import of energy by choosing a ground source heat pump (GSHP) to cover space heating, via underfloor heating, and heating of water. During summer, free cooling is taken from the bore holes for the GSHP. Cooling is supplied via the ventilation system. One GSHP per building.
3. Generation of electricity by installing photovoltaic panels (PV-panels), on the roof facing south.

Simulations were conducted with VIP Energy [11], validated with ASHRAE 140 [12]. A summary of a technical description is given in Table 1 and results from simulations are presented in Table 2.

It shall be noted that weighting factors should be used in the Swedish NetZEB balance calculations [13], where 2.5 may be a Primary Energy Factor (PEF) used. However, in this analysis no weighting factors are applied as the building only demands and generates electricity.

Furthermore, electricity for plug loads and lighting are not included in the Swedish NetZEB balance. I.e. the generation from the PV-panels should cover the energy use, excluding plug loads and lighting.

Table 1. Summary of technical description of case study. All values are design values except for air tightness.

Type of data/description	Value
Conditioned area	258 m^2
Enclosing area/conditioned area	2.88
Mean U-value for building envelope[1]	0.17 W/m^2K
Air tightness, measured (q_{50} & n_{50})	0.21 l/s, m^2 & 0.84 h^{-1}
HRV (heat recovery & specific fan power)	90 % & 1.5 kW/m^3s
Ventilation rate	92 l/s & 0.5 h^{-1}
GSHP, Seasonal coefficient of performance (SCOP)	3.0
Photovoltaic panels (area/power)	66 m^2/10 kWp

Table 2. Results from simulations for the case study

Energy use	kWh/year	kWh/m^2a
Fans	1 546	6.0
Pumps (including cooling)	934	3.6
GSHP (space heating and hot water)	5 214	13.6
Total energy demand, excluding plug loads and lighting (disregarding PV-panels)	**7 694**	**29.8**
Plug loads and lighting	7 766	30.1
Electricity from PV-panels, direct use	-3 832	-14.9
Electricity from PV-panels, exported	-4 053	-15.7

3 Failure description

During the first winter, some residents complained about low indoor temperature when the outdoor temperature dropped below somewhere in-between -5°C and -10°C. They also complained regarding the supply air temperature, which they said were much too low.

After some investigation the reason for the problem were discovered; the condensing extract air were forming ice and blocking the heat exchanger.

This subject is not new, and HRV manufactures have developed different strategies to prevent or limit the build-up of ice and frost in heat exchangers, which has been highlighted and discussed before [14-16]. Common strategies may be Recirculation, Supply fan shut off and Supply air preheating.

In these ventilation units, the defrost strategy was supply fan shut off. This strategy means that the supply air fan stops, while extract air fan continues to run. I.e. the warm extract air defrosts the heat exchanger.

1 Including thermal bridges, windows and doors

This strategy assumes, when the supply fan stops, that supply air partly finds its way into the dwelling through imperfections in the building envelope, see Figure 2. However, in this case, the building envelope were very airtight (see Table 1).

Since the building envelope were air tight, the supply air mainly came via the supply air ducts and inlet, even though the supply air fan were shut off.

This resulted in build-up of frost and ice in the heat exchanger and low supply air temperature. The consequence of the low supply air temperature were initially limited discomfort, due to low supply air temperature. However, in this project, the HVAC design engineer had assumed that the supply air would not drop below +15°C. When the supply air fell to low temperatures, roughly under +10°C, the underfloor heating system were not able to compensate for the low supply air temperature, and the temperature in the dwellings dropped, causing high discomfort for the residents.

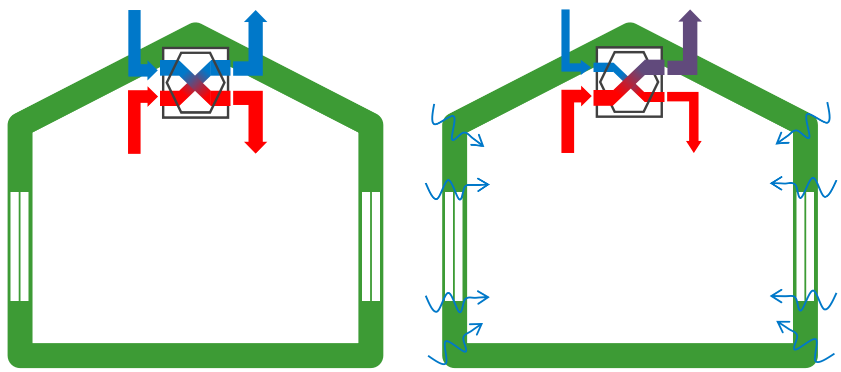

Fig. 2. Schematic description of assumed air flows. Left: Normal use, balanced ventilation. Right: Defrosting mode, Supply fan shut off.

4 Action and evaluation

4.1 Chosen technical solution

When the problems occurred. The subcontractor of ventilation and heating (the same subcontractor) were contacted and ask to suggest a technical solution to overcome the problem. Hence, the subcontractor were bound to ensure >+21°C indoor temperature, at -15°C outdoor temperature.

The subcontractor contacted the supplier and asked for a solution. Initially the supplier suggested to pre-heat the outdoor/fresh air, with an electric pre-heater (1 kW), to ensure no frosting- and freezing problems. However, in the initial suggested solution, the activation of the preheater would be based on the temperature of the outdoor/fresh air (Left in Figure 4) and start heating when the temperature dropped under -1°C. Based on the outdoor temperature a normal year (See Figure 3) and the suggested installed power. This solution were expected to increase the yearly energy use by 1 000 – 2 000 kWh/ventilation unit, and therefore rejected.

After some discussion, the subcontractor found out that the initial given information were wrong/misunderstood. The temperature sensor were actually placed after the pre-heater unit (Right in Figure 4). This would mean that the preheater would shut off as soon as the temperature after the preheater exceeded -1°C. This was expected to vastly reduce the energy consumption, and the decision was made to test the solution. The pre-heaters were mounted and measurement and evaluation started in March.

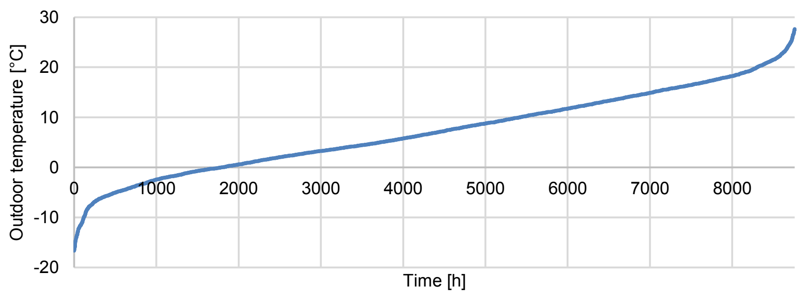

Fig. 3. Duration diagram of outdoor air a Typical Metrological Year (TMY)

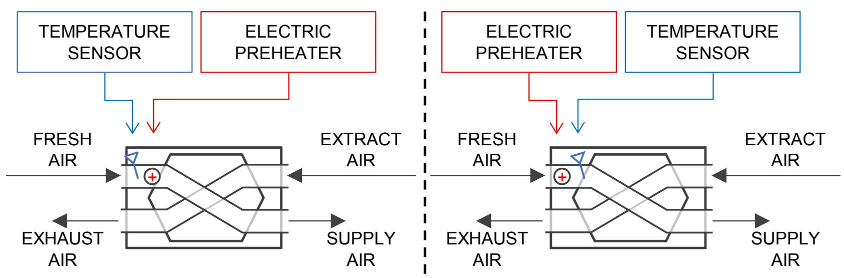

Fig. 4. Schematic description regarding position of temperature sensor and electric preheater. Left: First suggestion given by the manufacturer. Right: The installed and evaluated solution.

4.2 Evaluation of increased energy use for pre-heaters

Already before problems occurred, total electricity use were measured in each dwelling. However, including plug loads, lighting and electricity for ventilation units. Evaluation of increased energy use due to installed pre-heaters were decided to be carried out in two different ways:

1. Total electricity use in six of seven houses, between 3 A.M. and 5 A.M. were analysed, as it was assumed that the total electricity use in each dwelling during that time would be rather stabile, except when the pre-heater would be needed.
2. New electricity meters were mounted on two of ventilation units, to get detailed results.

4.3 Evaluation of energy use

One of the houses which did not have problems with the ventilation were monitored in detail. Starting in March 2015, energy use and energy generation were measured and is still ongoing.

5 Results from measurements

5.1 Pre heating

The results from measurements of total energy use is presented in Figure 5. Based on the average energy use in all dwellings. It was concluded that the energy use for fans, refrigerators, stand-by for TVs, etc. (I.e. when there were no active use of owens, computers, etc.) were 165 kWh/h, dwelling between 3 A.M. and 5 A.M. This is roughly equal to 1.9 W/m^2, conditioned area.

Based on energy use before the pre-heaters were mounted (left in Figure 5) it was possible to investigate increased energy use related to outdoor temperature. The average increase of energy use between 3 A.M. and 5 A.M were gathered (right in Figure 5). Based on the equation for the interpolation (right in Figure 5) and TMY for the location (Figure 3), the increased energy use (due to pre-heaters) were calculated to 1.2 kWh/m^2a.

The standard error (SE) for the equation (right in Figure 5) is 0.047 kWh/h, dwelling. Using the maximum and minimum values for standard error the uncertainty is calculated to ± 0.6 kWh/m^2a, or 50 %.

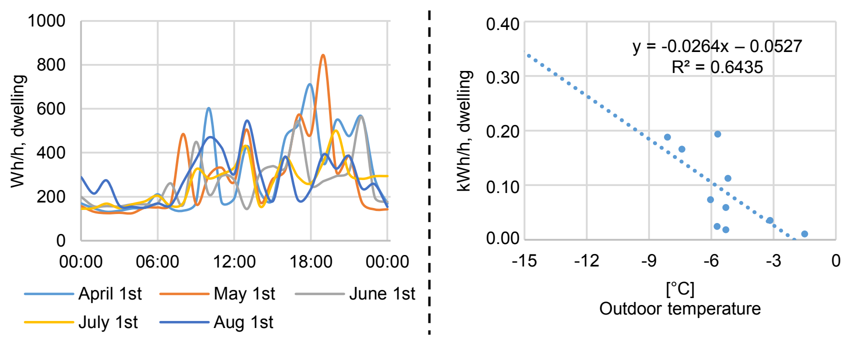

Fig. 5. Left: Average electricity use per dwelling in Solallén, before pre-heaters. Right: Average increased energy use in relation to outdoor temperature, between 3 A.M. and 5 A.M.

The results from the detailed measurements from one of the ventilation unit is presented in Figure 6. Also here, only data between 3 A.M. and 5 A.M. is included. Hourly data is presented. Energy use at outdoor temperatures below -2°C is separated from energy use at outdoor temperatures above -2°C. The mean energy use for the ventilation unit at outdoor temperatures above -2°C were 0.036 kWh/h. Which corresponds to a specific fan power of 1.2 kW/m^{3}s (This ventilation unit had a ventilation rate of 0.03m^3/s) or 0.4 W/m^2, conditioned area. Based on the equation for the interpolation (Figure 6) and TMY for the location (Figure 3), the increased energy use (due to pre-heaters) were calculated to 0.8 kWh/m^{2}a.

The standard error (SE) for the equation (in Figure 6) is 0.022 kWh/h, dwelling. Using the maximum and minimum values for standard error the uncertainty is calculated to ± 0.2 kWh/m^{2}a, or 25 %.

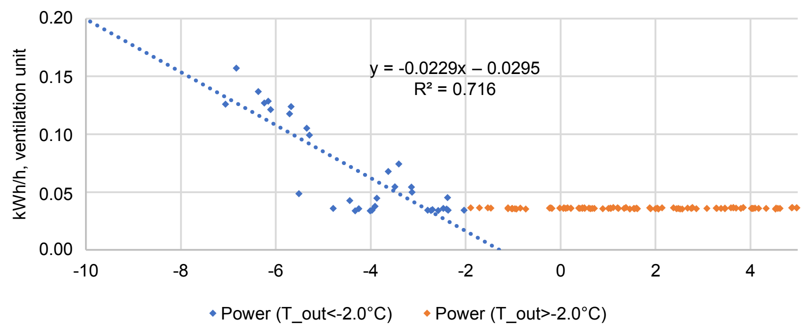

Fig. 6. Energy use for ventilation unit after mounting of pre-heater in relation to outdoor temperature.

5.2 Energy performance

In Figure 7, results from simulations and measurements is presented. Energy use for GSHP were 3 kWh/m^{2}a higher compared to simulations. However, the main reason for higher energy use were lower inter heat loads due to plug loads and lighting, which were 8 kWh/m^{2}a lower compared to simulations. Electricity generation from PV-panels were 5 kWh/m^{2}a higher compared to simulations. The main reason for the higher energy generation were higher solar radiation, 10 % higher compared to TMY. Energy use for fans were almost 2 kWh/m^{2}a lower compared to simulation. The main reason for the lower energy use were more efficient fans compared to procurement/design requirements.

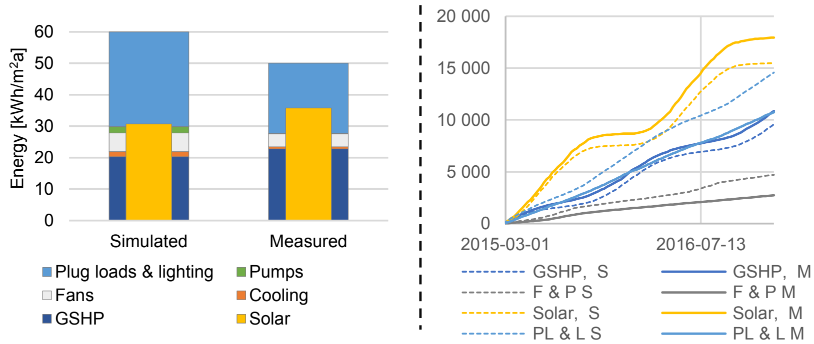

Fig. 7. Left: Comparison of annual energy use and solar energy generation simulated and measured. Right: Comparison of accumulated energy, generation and simulation. GSHP = Ground source heat pump, F&P = Fans and pumps, P&L = Plug loads and lighting.

6 Discussion and conclusions

The case study clearly shows that it is possible to build Net ZEB with existing technologies. However, it also shows that a previously proven working defrosting strategy, "supply fan shut off", does not work. Hence, it highlights the importance of considering the secondary effects which may occur striving towards Net ZEBs. It is not always suitable to follow "rules of thumb".

Based on measuring of total energy use, the installed pre-heaters may be expected to increase the energy use in this project, by 1.2±0.6 kWh/m^{2}a. Based on detailed measurements from one of the ventilation unit, the installed pre-heaters may be expected to increase the energy use in this project, by 0.8±0.2 kWh/m^{2}a. In relative terms, the deviation/uncertainty is rather high 50 % and 25 % respectively. However, even in a worst case scenario, the increased energy use is lower than the surplus from energy generation and energy use. I.e. the Net ZEB balance is still reached.

The measurements were conducted in the end of the Swedish winter. I.e. the chosen solution has not been evaluated for outdoor temperatures below -10°C. However, based on the installed capacity of the pre-heaters (1 kW) and air flow 30 l/s, the chosen technical solution is expected to ensure good indoor comfort when temperature is dropping below -10°C. The pre-heater should enable a temperature increase of the outdoor air, before it reaches the heat exchanger, of roughly 25 °C, preventing frost down to outdoor temperatures of -25°C (which is not normal in this part of Sweden).

Secondary effects are hard to predict and investigate. More research is needed and more time is needed in the design phase of building projects, especially in Net ZEB projects.

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