Is it possible to build near zero energy single family buildings in very cold arctic climate?

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Abstract. According to the Energy Performance of Buildings Directive recast of 2010 all new buildings in European Union shall be nearly zero energy buildings from 2021 and onwards. However only very few of the countries in the Europan Union have to deal with very cold arctic climatic conditions, i.e. Sweden and Finland. Further, the required energy performance of a nearly zero energy building should be calculated on the basis of a methodology, which may be differentiated at national and regional level. This means that the definition may be quite different from member state to member state. This paper presents how different solutions regarding design of building envelopes combined with different heating and ventilation systems in single-family buildings can meet the energy requirements for nearly zero energy buildings. The main focus is on how the proposed Swedish building regulations for nearly zero energy buildings affects the possibility to build single-family buildings in the very north arctic part of Sweden. The main conclusions from this study is that the building envelopes in most cases need to be improved compared today existing standard and that direct electric heating will not be an option. Further, also with improved building envelopes solutions with extract air heat pumps will have difficulties in meeting the tougher energy requirements, especially in single-storey buildings. However geothermal heat pumps will meet the requirements even with existing building envelopes and even with only exhaust ventilation without heat recovery. Also air-water heat pumps combined with ventilation heat recovery can meet the requirement.

Keywords: Nearly zero energy, Energy performance, Arctic climate, Heat pump, Mechanical ventilation

1 Background

According to the Energy Performance of Buildings Directive recast of 2010 [1] all new buildings in the European Union shall be nearly zero energy buildings from 2021 and onwards. However only very few of the countries in the Europan Union have to deal with very cold arctic climatic conditions, i.e. Sweden and Finland. Further, the required energy performance of a nearly zero energy building should be calculated on the basis of a methodology, which may be differentiated at national and regional level. This means that the definition may be quite different from member state to member state. After years of investigations Boverket – the National Board of Housing, Building and Planning – finally presented a Swedish definition of nearly zero energy building in the summer of 2017 [2]. However a final determination of primary energy factors to be used in 2021 remains to be decided. Thus this study has used the values that were proposed by Boverket in the spring of 2017.

2 Purpose

The purpose of this paper is to presents how different solutions regarding design of building envelopes combined with different heating and ventilation systems in single-family buildings can meet the proposed energy requirements for nearly zero energy buildings in Sweden. The main focus is on how the proposed Swedish building regulations for nearly zero energy buildings affects the possibility to build single-family buildings, especially in the very north arctic part of Sweden.

3 Method

Different solutions regarding design of building envelopes have been combined with different heating and ventilation systems. The energy use for the different combinations has then been calculated using the energy calculation program TMF Energi [3]. Based on these results the energy performance has been calculated and compared with the proposed Swedish requirements for nearly zero energy buildings.

3.1 Description of the studied single family houses

The purpose of the study was to see how the Swedish definition of a near zero energy buildings, the proposed factors and maximum primary energy number for 2021 affects the possibility to design different building envelopes in combination with different heating and ventilation systems. Values for different possible building designs from very compact, extremely well insulated and air-tight envelopes to less compact and less insulated and air-tight envelopes have been developed. These different building designs have been combined with several heating and ventilation systems.

The building physic properties of the houses. The first building type to be studied is very compact single-storey buildings of different sizes and with two levels of thermal insulation and air-tightness. Table 1 shows values for an improved envelope performance compared to today standard, but still with reasonable additional costs. Table 2 shows values for an extreme building envelope where the additional costs may not be justified. With the same building system the U_m-value increases somewhat as A_{temp} decreases and the ratio A_{om}/A_{temp} is also increased. This is the reason why Boverket allows higher primary energy numbers when A_{temp} is below 130 m^2.

Table 1. Very compact, well insulated and air-tight single-storey house.

Tempered floor area (A_{temp}), m^2	90	130	160
Number of rooms and kitchen, -	3	4	5
Building inside envelope area (A_{om}) , m^2	283.3	386.1	463.3
Average thermal transmittance (U_m), $W/m^2 K$	0.212	0.205	0.202
Average air leakage rate at (q_{50}), l/s m^2	0.30	0.30	0.30

Table 2. Very compact, extremely well insulated and air-tight single-storey house.

Tempered floor area (A_{temp}), m^2	90	130	160
Number of rooms and kitchen, -	3	4	5
Building inside envelope area (A_{om}) , m^2	283.3	386.1	463.3
Average thermal transmittance (U_m), $W/m^2 K$	0.168	0.163	0.160
Average air leakage rate at (q_{50}), l/s m^2	0.15	0.15	0.15

The second building type to be studied is a single-storey single-family house with an angular extension and with three different levels of thermal insulation and air-tightness; today standard, improved standard and extreme standard.

Table 3. Single-storey single-family house with an angular extension.

Tempered floor area (A_{temp}), m^2	160	160	160
Number of rooms and kitchen, -	5	5	5
Building inside envelope area (A_{om}) , m^2	500	500	500
Average thermal transmittance (U_m), $W/m^2 K$	0.24	0.20	0.16
Average air leakage rate at (q_{50}), l/s m^2	0.60	0.30	0.15

The third building type to be studied is a 1½ storey single-family house with an angular roof extension and with three different levels of building standard. This is today the most common single family building type.

Table 4. 1½-storey single family house with an angular roof extension

Tempered floor area (A_{temp}), m^2	160	160	160
Number of rooms and kitchen, -	5	5	5
Building inside envelope area (A_{om}) , m^2	400	400	400
Average thermal transmittance (U_m), $W/m^2 K$	0.26	0.22	0.18
Average air leakage rate at (q_{50}), l/s m^2	0.60	0.30	0.15

The fourth building type to be studied is a very compact 2 storey single-family house and with three different levels of building standard.

Table 5. Very compact 2-storey single family house

Tempered floor area (A_{temp}), m^2	160	160	160
Number of rooms and kitchen, -	5	5	5
Building inside envelope area (A_{om}) , m^2	350	350	350
Average thermal transmittance (U_m), $W/m^2 K$	0.27	0.23	0.19
Average air leakage rate at (q_{50}), $l/s\ m^2$	0.60	0.30	0.15

The heating and ventilation systems studied. Nine different heating and ventilation systems have been studied. Some of them are the most commonly used today and other are expected to be used more as the energy requirements are getting tougher.

For all studied systems the today best available technologies are assumed to be used, i.e. very energy efficient pumps and fans, inverter controlled compressors, low stand-by power, very well insulated ducts, pipes and hot water storage, feedback space heating control, very efficient ventilation heat recovery and demand controlled ventilation (when applicable). The main parts of the systems are placed in the insulated part of the building envelope. The different heating and ventilation systems studied are described in table 6 together with the abbreviations used in the results section.

Table 6. Description of the heating and ventilation systems studied

System	Abbreviation
Geothermal heat pump + Exhaust air	GHP+E
Geothermal heat pump + Exhaust and supply air with heat recovery	GHP+ESH
Air-water heat pump + Exhaust air	AWHP+E
Air-water heat pump + Exhaust and supply air with heat recovery	AWHP+ESH
Electricity + Thermal solar + Exhaust and supply air with heat recovery	EL+TS+ESH
Exhaust air heat pump + Peak electric heating	EHP+EL**
Exhaust air heat pump + Peak district heating	EHP+DH
District heating + Exhaust and supply air with heat recovery	DH+ESH
Biofuel heating + Thermal solar + Exhaust and supply air with heat recovery	BF+TS+ESH

**) A more simple exhaust air heat pump that keeps the exhaust air above 0°C.

3.2 Description of the calculation program used

All energy calculations has been made with a for the purpose modified version of the energy calculation program TMF Energi [3]. It is a calculation tool developed by RISE, Research Institutes of Sweden (former SP) [4], for TMF, the national trade and employers' association of the wood processing and furniture industry in Sweden, for calculation of specific energy use in single family houses according to the energy requirement in the Swedish building regulations. It has been used for more than ten years and has been updated regularly along with changes in the building regulations. It is used by a majority of the manufacturers of detached single-family houses.

3.3 Description of the Swedish definition of near zero energy buildings

The definition of nearly zero energy buildings in Sweden is given by Boverket in its latest mandatory provisions and general recommendations, BBR 25 [2]. The energy performance is calculated as a primary energy number (EP_{pet}) according to the following formula:

$$EP_{\text{pet}} = \frac{\sum_{i=1}^{6}\left(\frac{E_{\text{uppv,i}}}{F_{\text{geo}}} + E_{\text{kyl,i}} + E_{\text{tvv,i}} + E_{\text{f,i}}\right) \times PE_{\text{i}}}{A_{\text{temp}}}$$

Where;

$E_{uppv,i}$	is the space heating energy for energy carrier i
$E_{kyl,i}$	is the space comfort cooling energy for energy carrier i
$E_{tvv,i}$	is the domestic hot water heating energy for energy carrier i
$E_{f,i}$	is the building property energy for energy carrier i
F_{geo}	is a geographic adjustment factor
PE_i	is the primary energy factor for energy carrier i
A_{temp}	is the ”floor area” intended to be heated to more than 10 ºC

Each municipality has been allocated a geographical adjustment factor to compensate for their different climate conditions. The geographical adjustment factors are in the range from 0.8 in the very south to 1.9 in the very north. This means that the same maximum primary energy number can apply for all single-family houses regardless of in which municipality it is built. In this study 0.8 applies to Malmö, 1.0 applies to Stockholm and 1.9 applies to Kiruna.

In BBR 25 the primary energy factor for electricity is set to 1.6 and for all other energy carries it is set to 1.0. In the spring of 2017 Boverket proposed that in 2021 the primary energy factor for electricity shall set to 2.5 and for all other energy carries it shall remain at 1.0. But as the primary energy factor for electricity in Europe is expected to be about 2.0 in 2021 many respondents had objections about this. Hence a final determination of primary energy factors to be used in 2021 remains to be decided. However if the primary energy factor for electricity is decreased it is likely that the primary energy factors for other energy carriers is also decreased as well as the maximum allowed primary energy number. The ratio between electricity and other energy carriers as well as the required energy performance will then in practice remain the same. In this study the primary energy factors proposed by Boverket for 2021 has been used as well as the proposed maximum primary energy number. For single-family houses the proposed maximum primary energy number is 90 kWh/m^2 a if the heated floor area is above 130 m^2, linearly increased to 110 kWh/m^2 a as the heated floor area is decreased to 90 m^2 and 110 kWh/m^2 a if the heated floor area is below 90 m^2, In addition to the requirements above the building regulations also have requirements on the maximum installed electric power for heating, ventilation and hot water production. These requirements also remains to be decided for 2021, but it is likely that they for single-family houses will remain almost the same as in BBR 25 and as the energy requirements gets tougher the requirements on maximum installed electric power will in most cases not imply a limitation.

A third requirement in the building regulation is on the average thermal transmittance of the building envelope. The maximum allowed average thermal transmittance is proposed to decrease from 40 to 30 W/m^2 K in 2021. However, this is also not a limitation as in almost all cases a much better building envelope is required to meet the proposed maximum primary energy number.

3.4 Determination of normal use during a normal year

A determination of normal use of different building types during a normal year is given by Boverket in its mandatory provisions and general recommendations, BEN 2 [5]. It is a new regulation establishing how to calculate energy use during normal use of a building during a normal year and how to normalize the measured energy consumption during any year to a normal usage and to a normal year. The main rule of the Swedish building regulations is that the energy performance shall be verified by measurements within two years of completion, but it is also possible to verify by calculations on a completed building. For a single-family house BEN 2 states the following standardized values for normal use:

Use of household electricity	30	kWh/m^2 a
Use of domestic hot water	18-20	kWh/m^2 a
Indoor temperature (minimum)	21	°C

Furthermore each Swedish municipality has been assigned a specific standardized climatic condition for a normal year to be used both for calculation of and normalization of measured energy use.

4 Results

The results of the calculations are presented in Table 7-21. Calculated primary energy numbers that meets the proposed required level for near zero energy buildings are marked in bold green. Calculated values that do not meet the required level are marked in bold red and values on the verge of meeting the requirements are marked in bold orange. As the primary energy number is a rather abstract value without any direct correlation with the real energy consumption of the houses, the bought energy including household electricity is also presented in each table. The total bought energy is presented as well as divided into electricity, district heating and biofuel where applicable.

4.1 Single storey very compact single family houses

Well-insulated and air-tight houses of different sizes. For these houses the heating and ventilation systems direct electricity (EL+TS+ESH) and exhaust air heat pump with peak electric heating (EHP+EL) fail to meet the suggested requirement level for near zero energy buildings. Exhaust air heat pump with peak district heating (EHP+DH) is on the verge to meet the requirement for the 90 m^2 house but does not meet it for the larger houses. Biofuel heating with thermal solar, supply and exhaust ventilation with heat recovery (BF+TS+ESH) are on the verge to meet the requirement for the 130 m^2 house and meet the requirement for the larger and the smaller house. The systems with geothermal heat pumps and meets the requirement for all house sizes, even without ventilation heat recovery.

Table 7. Atemp **90** m^2 (U_m 0.212 W/K m^2, q_{50} 0.30 l/s m^2). $EP_{pet, max}$ **110** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**73.8**	**72.0**	**100.0**	**92.4**	**146.2**	**119.3**	112.8	**93.4**	**96.1**
BE_{total}	6706	6401	8813	8102	13180	9819	13192	15624	14626
$BE_{electr.}$	6706	6401	8813	8102	13180	9819	7132	3125	3317
$BE_{distr.}$	-	-	-	-	-	-	6059	12499	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	11309

Table 8. A_{temp} **130** m^2 (U_m 0.205 W/K m^2, q_{50} 0.30 l/s m^2), $EP_{pet, max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**69.3**	**67.2**	**85.2**	**85.3**	**135.7**	**112.0**	**104.4**	**86.7**	88.3
BE_{total}	9250	8784	11320	11004	17717	13486	19340	20965	19710
$BE_{electr.}$	9250	8784	11320	11004	17717	13486	8767	4498	4690
$BE_{distr.}$	-	-	-	-	-	-	10573	16467	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	15021

Table 9. A_{temp} **160** m^2 (U_m 0.202 W/K m^2, q_{50} 0.30 l/s m^2), $EP_{pet, max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**67.8**	**65.1**	**82.5**	**83.2**	**130.9**	**108.9**	**103.1**	**83.6**	**84.8**
BE_{total}	11200	10566	13610	13267	21063	16235	25040	24905	23460
$BE_{electr.}$	11200	10566	13610	13267	21063	16235	9690	5527	5719
$BE_{distr.}$	-	-	-	-	-	-	15350	19378	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	17741

Extremely well-insulated and air-tight houses of different sizes. Also for these houses the heating and ventilation system direct electricity (EL+TS+ESH) fail to meet the suggested requirement. Exhaust air heat pump with peak electric heating (EHP+EL) are on the verge to meet the requirement for the 130 m^2 house and meet the requirement for the larger and the smaller house. Exhaust air heat pump with peak district heating (EHP+DH) meet the requirement for the 90 m^2 house and are on the verge to meet the requirement for the larger houses. All other heating and ventilation systems meet the requirement.

Table 10. A_{temp} **90** m^2 (U_m 0.168 W/K m^2, q_{50} 0.15 l/s m^2), $EP_{pet, max}$ **110** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**66.5**	**62.6**	**87.5**	**80.3**	**115.5**	**94.9**	**98.5**	**75.7**	**76.9**
BE_{total}	6228	5801	7972	7289	10711	8276	11124	12666	11788
$BE_{electr.}$	6228	5801	7972	7289	10711	8276	6920	3104	3296
$BE_{distr.}$	-	-	-	-	-	-	4204	9562	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	8492

Table 11. A_{temp} **130** m^2 (U_m 0.163 W/K m^2, q_{50} 0.15 l/s m^2), $EP_{pet, max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**62.6**	**58.7**	**82.3**	**74.1**	**107.9**	**90.2**	**91.6**	**70.6**	**70.8**
BE_{total}	8624	8006	10993	9928	14482	11497	16533	17107	15966
$BE_{electr.}$	8624	8006	10993	9928	14482	11497	8585	4470	4662
$BE_{distr.}$	-	-	-	-	-	-	7947	12637	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	11304

Table 12. A_{temp} **160** m^2 (U_m 0.160 W/K m^2, q_{50} 0.15 l/s m^2), $EP_{pet, max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**60.8**	**56.8**	**81.1**	**71.3**	**103.8**	**87.6**	**90.6**	**68.1**	**67.7**
BE_{total}	10404	9628	13355	11872	17195	13842	21557	20302	18969
$BE_{electr.}$	10404	9628	13355	11872	17195	13842	9538	5494	5686
$BE_{distr.}$	-	-	-	-	-	-	12019	14808	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	13282

4.2 Less compact single-storey single -family house with an angular extension and with different insulation and air-tightness standard

For the house with today normal insulation and air-tightness standard it is only the geothermal heat pump that meets the requirement. The air-water heat pump combined with supply and exhaust ventilation and heat recovery (AWHP+ESH) is on the verge to meet the requirement for that house. The direct electric system (EL+TS+ESH) and the systems with exhaust air heat pumps (EHP+EL, EHP+DH) do not meet the requirement even with the extreme building envelope. The systems with district heating (DH+ESH) and biofuel (BF+TS+ESH) are on the verge to meet the requirement with the improved building envelope and meet the requirement with the extreme envelope.

Table 13. A_{temp} 160 m^2 (U_m **0.24** W/K m^2, q_{50} **0.60** l/s m^2), $EP_{pet, max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**77.5**	**77.5**	**100.1**	89.7	**175.5**	**142.4**	**122.0**	**109.1**	**113.4**
BE_{total}	12403	12070	15707	14105	27436	20025	30393	32455	30931
$BE_{electr.}$	12403	12070	15707	14105	27436	20025	9881	5582	5773
$BE_{distr.}$	-	-	-	-	-	-	20511	26873	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	25158

Table 14. A_{temp} 160 m^2 (U_m **0.20** W/K m^2, q_{50} **0.30** l/s m^2), $EP_{pet, max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**68.7**	**67.5**	**86.0**	**84.1**	**138.9**	**116.8**	**107.3**	88.2	89.9
BE_{total}	11386	10848	14027	13428	22214	17119	26222	26271	24804
$BE_{electr.}$	11386	10848	14027	13428	22214	17119	9736	5537	5729
$BE_{distr.}$	-	-	-	-	-	-	16486	20734	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	19075

Table 15. A_{temp} 160 m^2 (U_m **0.16** W/K m^2, q_{50} 0.**15** l/s m^2), $EP_{pet, max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**62.8**	**58.8**	**80.3**	**75.3**	**110.5**	**93.7**	**94.3**	**71.9**	**71.9**
BE_{total}	10633	9859	13337	12339	18146	14531	22597	21436	20069
$BE_{electr.}$	10633	9859	13337	12339	18146	14531	9587	5502	5694
$BE_{distr.}$	-	-	-	-	-	-	13010	15935	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	14374

4.3 1½-storey single -family house with an angular roof extension and with different insulation and air-tightness standard

For the house with today normal insulation and air-tightness standard it is only the systems with geothermal heat pump (GHS+E, GHS+ESH) and the air-water heat pump combined with supply and exhaust ventilation and heat recovery (AWHP+ESH) that meets the requirement. The system with air-water heat pump and ventilation heat recovery (AW+ESH) are on the verge to meet the requirement. The direct electric system (EL+TS+ESH) do not meet the requirement even with the extreme building envelope. Systems with exhaust air heat pumps (EHP+EL, EHP+DH) meet or are at the verge of the requirement with the extreme building envelope. The systems with district heating (DH+ESH) and biofuel (BF+TS+ESH) meet the requirement with the improved building envelope.

Table 16. A_{temp} 160 m^2 (U_m **0.26** W/K m^2, q_{50} **0.60** l/s m^2), $EP_{pet,\ max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**83.4**	**81.0**	**89.7***	**84.8**	**151.8**	**121.4**	**110.7**	**95.6**	**98.2**
BE_{total}	13359	12647	14459	13512	24050	17625	27177	28447	26954
$BE_{electr.}$	13359	12647	14459	13512	24050	17625	9776	5555	5747
$BE_{distr.}$	-	-	-	-	-	-	17401	22892	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	21207

*) The maximum electric power for heating and domestic hot water may be too high.

Table 17. A_{temp} 160 m^2 (U_m **0.22** W/K m^2, q_{50} **0.30** l/s m^2), $EP_{pet,\ max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**75.2**	**70.3**	**84.7**	**78.7**	**123.1**	**102.1**	**99.5**	**79.2**	**79.8**
BE_{total}	12312	11408	13852	12731	19948	15464	24033	23580	22160
$BE_{electr.}$	12312	11408	13852	12731	19948	15464	9653	5517	5710
$BE_{distr.}$	-	-	-	-	-	-	14380	18063	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	16450

Table 18. A_{temp} 160 m^2 (U_m **0.18** W/K m^2, q_{50} **0.15** l/s m^2), $EP_{pet,\ max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**68.4**	**62.0**	**79.7**	**69.2**	**100.8**	**85.2**	**89.3**	**66.3**	**65.8**
BE_{total}	11528	10443	13182	11624	16760	13572	21186	19783	18468
$BE_{electr.}$	11528	10443	13182	11624	16760	13572	9522	5490	5683
$BE_{distr.}$	-	-	-	-	-	-	11664	14293	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	12785

4.4 2-storey very compact single-family house with different insulation and air-tightness standard

The systems with district heating (DH+ESH) and biofuel (BF+TS+ESH) are on the verge to meet the requirement with the standard building envelope and meet the requirement with the improved envelope. The systems with district heating (DH+ESH) and biofuel (BF+TS+ESH) are on the verge to meet the requirement with the standard building envelope. The direct electric system (EL+TS+ESH) do not meet the requirement even with the extreme building envelope. Systems with exhaust air heat pumps (EHP+EL, EHP+DH) meet the requirement with the extreme building envelope.

Table 19. A_{temp} 160 m^2 (U_m **0.27** W/K m^2, q_{50} **0.60** l/s m^2), $EP_{pet,\ max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**78.1**	**74.5**	**84.0***	**81.9**	**138.5**	**109.6**	**104.2**	**88.0**	**89.7**
BE_{total}	12699	11952	13776	13105	22145	16300	25351	26189	24723
$BE_{electr.}$	12699	11952	13776	13105	22145	16300	9708	5539	5731
$BE_{distr.}$	-	-	-	-	-	-	15643	20649	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	18992

Table 20. A_{temp} 160 m^2 (U_m **0.23** W/K m^2, q_{50} **0.30** l/s m^2), $EP_{pet,\ max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**70.5**	**65.7**	**80.4**	**73.3**	**113.7**	**93.8**	**94.7**	**73.8**	**73.9**
BE_{total}	11830	10926	13341	12105	18605	14526	22691	21983	20600
$BE_{electr.}$	11830	10926	13341	12105	18605	14526	9595	5506	5699
$BE_{distr.}$	-	-	-	-	-	-	13096	16477	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	14901

Table 21. A_{temp} 160 m^2 (U_m **0.19** W/K m^2, q_{50} **0.20** l/s m^2), $EP_{pet,\ max}$ **90** kWh/m^2a.

	GHP +E	GHP +ESH	AWHP +E	AWHP +ESH	EL+TS +ESH	EHP +EL	EHP +DH	DH +ESH	BF+TS +ESH
EP_{pet}	**64.9**	**58.6**	**75.9**	**65.5**	**94.5**	**79.8**	**85.8**	**62.7**	**61.8**
BE_{total}	11173	10109	12748	11190	15860	12966	20227	18707	17433
$BE_{electr.}$	11173	10109	12748	11190	15860	12966	9474	5482	5675
$BE_{distr.}$	-	-	-	-	-	-	10753	13225	-
$BE_{biof.}$	-	-	-	-	-	-	-	-	11758

5 Conclusions

The main conclusions from this study is that the building envelopes in most cases need to be improved compared today existing standard and that direct electric heating will not be an option. Further, also with improved building envelopes solutions with extract air heat pumps will have difficulties in meeting the tougher energy requirements in the very north arctic part of Sweden, especially in single-storey buildings. However geothermal heat pumps will meet the requirements even with today existing building envelope standard and even with only exhaust ventilation without heat recovery. But solutions with no preheating of the outdoor supply air are from a thermal comfort point of view not recommended in a cold arctic climate. Air-water heat pumps may in many cases also meet the Swedish requirement for near zero energy buildings if combined with ventilation heat recovery. The challenge for that solution in a very cold arctic climate is to not exceed the maximum allowed electric power for heating and domestic hot water when the heat pump is shut off.

References

1. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
2. Boverket´s building regulations – mandatory provisions and general recommendations, BFS 2011:6 with amendments up to BFS 2017:5 BBR 25 (in Swedish).
3. TMF Energi is a calculation tool developed by RISE (formerly SP) for TMF, the national trade and employers' association of the wood processing and furniture industry in Sweden, for calculation of energy use in single family buildings according to the energy requirement in the Swedish building regulations.
4. The RISE institutes Innventia, SP Technical Research Institute of Sweden and Swedish ICT have in 2017 merged into RISE Research Institutes of Sweden AB in order to become a stronger research and innovation partner for businesses and society.
5. Boverket´s regulations and general advice on determination of the energy consumption of the building in normal use during a normal year, BFS 2016:12 with amendments up to BFS 2017:6 BEN 2 (in Swedish).