Integrated Energy Design (IED)

Refurbishment Rotvoll Barn

Assignment 3

Integrated Energy Design process:

Introduction

This report provides a detailed energy performance analysis of the Rotvoll design project, together with specifications of the systems used, quality control plan and operational strategies for the building.

The project is about renovating an old barn in order to retrofit of a single unit building to ZEB standards. The barn is located on Camphill rotvoll's property between Leangen to the west and Ranheim to the east. Camphill Rotvoll is after an attractive concept to use the barn as a part of the residential and working community for people with special needs.

Conceptually a zero emission building (ZEB) is a building with a greatly reduced energy demand and able to generate or harvest energy on site, producing enough to achieve a carbon neutral balance. A net zero-energy balance is another concept, being a net zero-energy building refers to a building that is self sufficient on an annual basis. According to a Norwegian study from 2011, "a clear and agreed definition of ZEB is yet to be achieved, both in Norway and internationally." [1]

We have set our main priority goal to focus on energy from operation and in this report, the possibility of reaching an nNZEB-OP is investigated; nearly zero emission building from operation. That is a building that has net zero carbon emissions from energy consumption over the course of one year. That means energy is harvested on-site, producing as much energy as is consumed and some more to compensate for any delivered energy (import).

Emissions during the operation of the building mainly consists of energy used for heating and electricity consumed by building services, lighting and other electric equipment. The division of consumption and production by energy source is what is important here, as different energy sources are credited to different CO2-emission factors. These work as credits when evaluating the credits of the building. In this investigation factors from a recent Norwegian ZEB-proposal are being used. [2]

Energy source	CO2 factor (g/kWh) [2]
Biofuel (solids)	14
District heating	231
Gas (fossile)	211
Oil (fossile	284

[1] "Proposal of a Norwegian ZEB definition: Assessing the implicatioin for design" (I. Sartori, T. H. Dokka, and Inger Andresen)
[2] "Proposal for CO2-factor for electricity and outline of a full ZEB-definition" (T.H. Dokka)

Energy budget

Below is the results from the final energy simulation on the detailed design of the Rotvoll barn. The energy budget is calculated with the energy simulation software SIMIEN. The energy sources chosen are a combination of biomass, solar thermal and PV-panels. The specific coverage is listed in the efficiency factor column.

	Energy post [kWh/m^2]	**Energy demand** [kWh/m^2 år]	**Efficiency factors** (-)	**Delivered energy** [kWh/m^2 år]	**Emission factors** [kg CO_2/kWh]	**Emissions** [kg CO_2/m^2 år]
1a	Space heating	17,1	90% Bio (0,73) 10% Sol El. (9)	21,1 0,19	0,014 0,395	0,295 0,079
1b	Ventilation heating	7,3	90% Bio (0,73) 10% Sol El. (9)	9,0 0,08	0,014 0,395	0,126 0,040
2	DHW	11,4	45% Bio (0,73) 45% Sol El. (9) 10% El. (0,9)	7,0 0,57 1,27	0,014 0,395 0,395	0,098 0,198 0,514
3a	Fans	6,1	100% El. (1,0)	6,1	0,395	2,410
3b	Pumps	1,1	100% El. (1,0)	1,1	0,395	0,435
4	Lighting	10,0	100% El. (1,0)	10,0	0,395	3,950
5	El. equipment	15,3	100% El. (1,0)	15,3	0,395	6,035
	SUM 1	68,3		71,7		14,20
	PV-production for el.			-34,6	0,395	-13,67
	PV-production for bio compensation.			-1,35	0,395	-0,534
	NET	**=**		**36,2 (Biomass)**		**0 (NZEB-OP)**

The energy budget is balanced by PV-production and show the amount of electricity generation that is necessary to reach nNZEB-OP, net zero emission from the operations of the building in the timespan of a year. Practically to reach this level of annual production an area of 800-1000m2 42 degree mounted PV-panels is necessary. It shows that it is reaching nNZEB is possible, but the economical viability and practical implications are not further investigated in this report.

Another important aspect is that even with this amount of PV-generation, the building still is not net zero energy. The chosen energy supply system, with biomass covering most of the heating demand is the cause of that. Biomass and solar thermal go well together, and biomass is generally considered to have a low CO2 impact, but as long as the biomass is not generated on site, it still needs to be delivered to the building. However the CO2 impacts of burning biomass for heating purposes can be compensated by generating electricity. This practise requires a feed in tariff, crediting the exported electricity to the grid. Such a system is not yet implemented in Norway. A possible solution could be to deliver electricity to adjacent buildings on the farm. This could also be part of a community based system for surplus energy.

2. Quality Assurance plan

In the beginning of IED process we were creating Quality Assurance plan to make sure that the energy and environmental goals set are met. Our main goal was to achiece Net Zero Energy Building and to achieve this we were following principles of passive house design. As requirements we have been using the minimum requirements for passivehouses in NS3700 and for the Norwegian building codes TEK-10 (small house/ residential/apartment block)

We have run evaluations according to the plan to adjust the performance of our design. The results are documented below in the list of specifications: First we have ranked our goals (priority no 1 is to achieve a net zero energy building) On the third field are documented requirements and the last column fourth is the current targets of our design.

In the energy evaluation we divided the building in a residential and a cultural part, the residential part reaches passivehouse standard, the cultural part (containing workshops and public functions on the ground floor), does not fulfill passivehouse requirements. This was expectedm because of a large use of glass with u-value of 1,2, that leads to a significant heat loss. However this part of the building is mainly used in the daytime, and the more detailed energy analysis where time-of-use, night sink of thermostats and solar gains in the buffer spaces are taken into considerations, this part still performs satisfactory. This part reaches low-energy level. (See the next section for more details.)

List of specifications

Priority	Goal	Min. Requirement	Current target
Goal I	NZEB	Minimum 70 % of the net heat demand must be covered with other energy sources than electricity and fossil fuels.	Renewable energy sources, green energy label A
Goal II	Passive house design	Maximum calculated net heating demand (Trondheim): Residential: 17,4 kWh/m² Cultural building: 25 kWh/m²	Residential: 11,4 kWh/m² Cultural building: 63,3 kWh/m²
Goal III	Comply with building codes TEK-10 (energy-framework).	Max annual net energy budget: 115 kWh/m² residential 165 kWh/m² cultural	Residential: 78,6 kWh/m² Cultural building: 98,6 kWh/m²
Goal IV	Healthy indoor environment	NS-EN15251	Class II

Priority	Goal	Min. Requirement	Current target
A0	**Reduce Heat Loss**		
A1		Compact building form, no excessive window area	Existing form of the barn. Retrofitting.
A2		Normalized thermal bridge value lower than: Residential: 0,03 W/m2K Cultural building: 0,03 W/m2K	Thermal bridge value:0,03 W/m K

A3		Air tightness: Leakage number at 50 Pa lower than: Residential: 0,60 h-1 Cultural building: 0,60 h-1	Infiltration (n50): 0,6 ACH
A4		Heat loss number less than: Residential: 0,50 W/m2K Cultural building: 0,50 W/m2K	Heat loss number: Residential: 0,34 W/m2K Cultural: 0,68 W/m2K
A5		Outer walls: U-value lower than: Residential: 0,15 W/m2K Cultural building: 0,15 W/m2K	Outer walls: Residential: 0,12 W/m2K Cultural building: 0,12 W/m2K Adjacent buffer walls: 0,2 W/m2K
A6		Roof: U-value lower than: Small house: 0,13 W/m2K Cultural building: 0,13 W/m2K	Roof: U-value lower than: Small house: 0,12 W/m2K Cultural building: 0,11 W/m2K
A7		Floor: U-value lower than: Small house: 0,15 W/m2K Cultural building: 0,15 W/m2K	Floor: U-value lower than: Residential: 0,12 W/m2K Cultural building: 0,12 W/m2K
A8		Windows and doors: U-value lower than: Small house: 0,80 W/m2K Cultural building: 0,80 W/m2K	Windows and doors: 0,70 W/m2K Cultural building: 0,96 W/m2K

Priority	**Goal**	**Min. Requirement**	**Current target**
B0	**Reduce Energy demand**		
B1		Ventilation heat recovery unit: Annual temperature efficiency higher than: 80 %	Heat recovery unit: 85 %
B2		Ventilation system: SFP-factor lower than: 1,5 kW/m3/s	SFP-factor: 1,5 kW/m3/s
B3		Space cooling = 0	See chapter climate data
B4		Cloth washers and dishwashers coupled to DHW	Reduce El. consumption, increase DHW consumption.
B5		Energy efficient lighting system	See energy calculation details

Priority	Goal	Min. Requirement	Current target
C0	**Utilize Solar Heat**		
C1		Winter sun penetrates into daytime use spaces	Organization of spaces. Floor plan
C2		Flexible shading. g-value system < 0,2 when activated	See energy calculation details
C2		Solar collectors	40m^2 = 50% of DHW. See energy calculation details

C3		PV-Panels	70m^2 = 7700 kWh. See energy calculation details

Priority	Goal	Min. Requirement	Current target
D0	**Display and control energy use**		
D1	Free cooling by natural ventilation, utilization of thermal mass, efficient control	User control cooling: educational function teaching environmental values to students (cooling via windows)	
D2	Minimized thermal loads from lights and equipment, utilization of daylight, occupancy control	Excellent appliances, User control: educational function teaching environmental values to students	

Priority	Goals	Min. Requirement to Acieve Goal	Current Target Value
E0	**Select energy source**		
E1		Biomass boiler	Covers remaining heating demand. See energy calculation details

Priority	Goals	Min. Requirement to Acieve Goal	Current Target Value
F0	**Indoor Environment**		
F1	Daylight conditions	Min. 2 % daylight factor on average floor area.	Daylight calculations. See delivery 2.
F2	Noise	Living room: 25-40 db. Bedroom 25-30 db.	Sound proofing between residential and workshops. See floor section details.
F3	Air quality Residential	Minimum requirements: In use: 1,2 m3/h/m2, Not in use: 0,7 m3/h/m2 Minimum for a bedroom: In use: 26 m3/h/bed, Rooms not for permanent residence: 0,7 m3/h/m2	See section 3 Ventilation rates.
F4	Air quality Cultural building	The sum of the following: People: 2,0 l/s per person + Materials: Low-emission materials: 0,7 l/s per m2, Normal-emission materials: 1,0 l/s per m2 and Activities: 1,0 l/s	See section 3 Ventilation rates.
F6	Air quality Recommendation	The maximum CO2-level should not exceed 1000 ppm with designed person load.	
F7	Indoor temperatures:	Operative temperature: The range can be between 19 °C and 26 °C, but should be between 19 °C and 22 °C	See energy simulations

F8	Thermal comfort in the summer:	The operative temperature level should not exceed 26 °C for more than 50 hours in a normal year.	See energy simulations
F9	Thermal stratification:	The difference between the temperatures at 1,1 m and 0,1 m (head and feet of a sitting person) should be kept below 3 °C.	

Energy calculation method and results

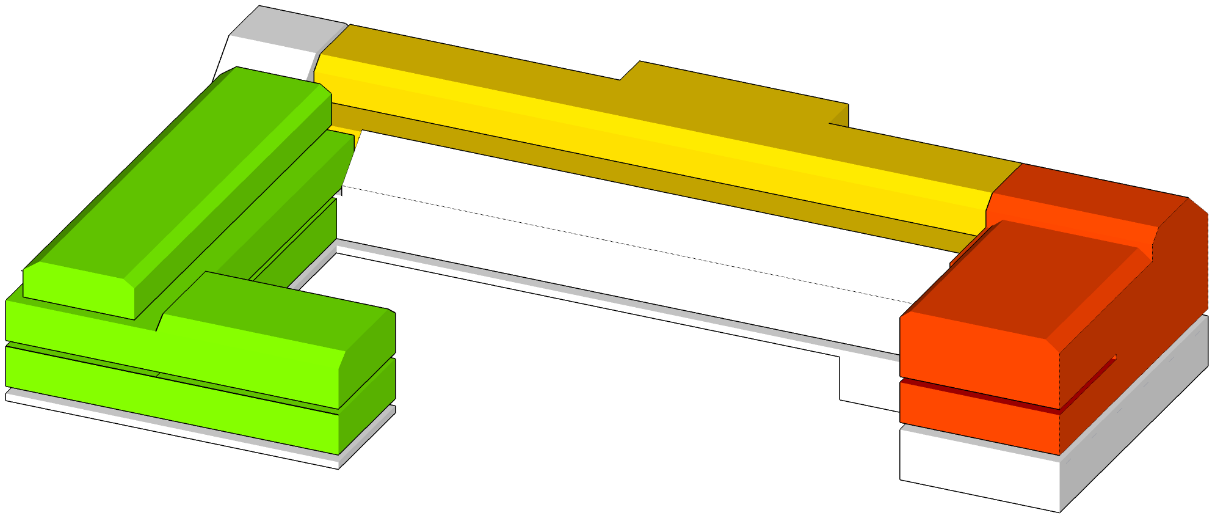


Figure 1, *energy simulation model for evaluation following the NS-3031 analogy, heated floor areas are displayed in accordance to zone colors. None heated areas are white. These are calculated as adjacent non-heated zones without solar contribution.*

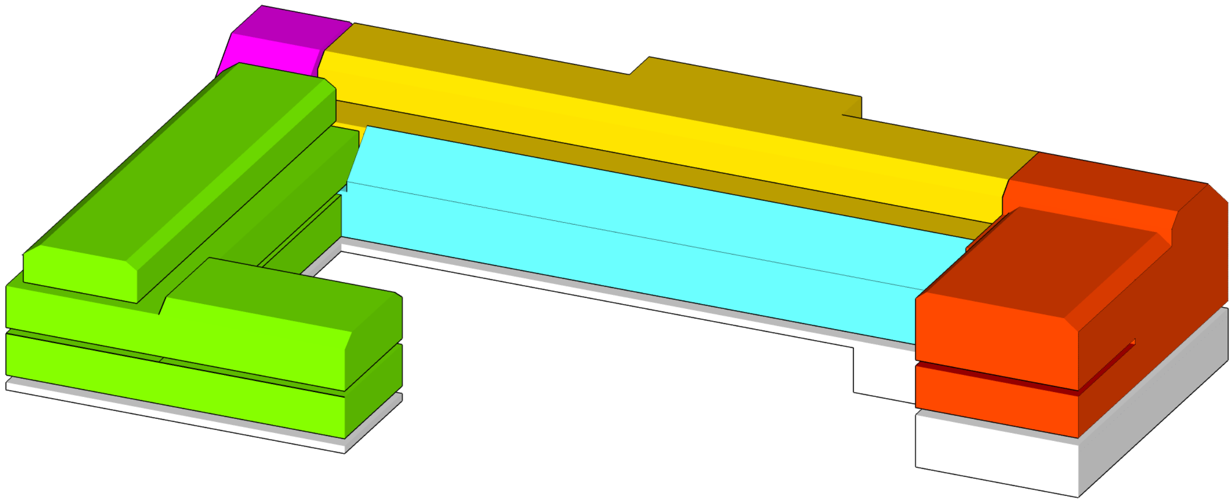
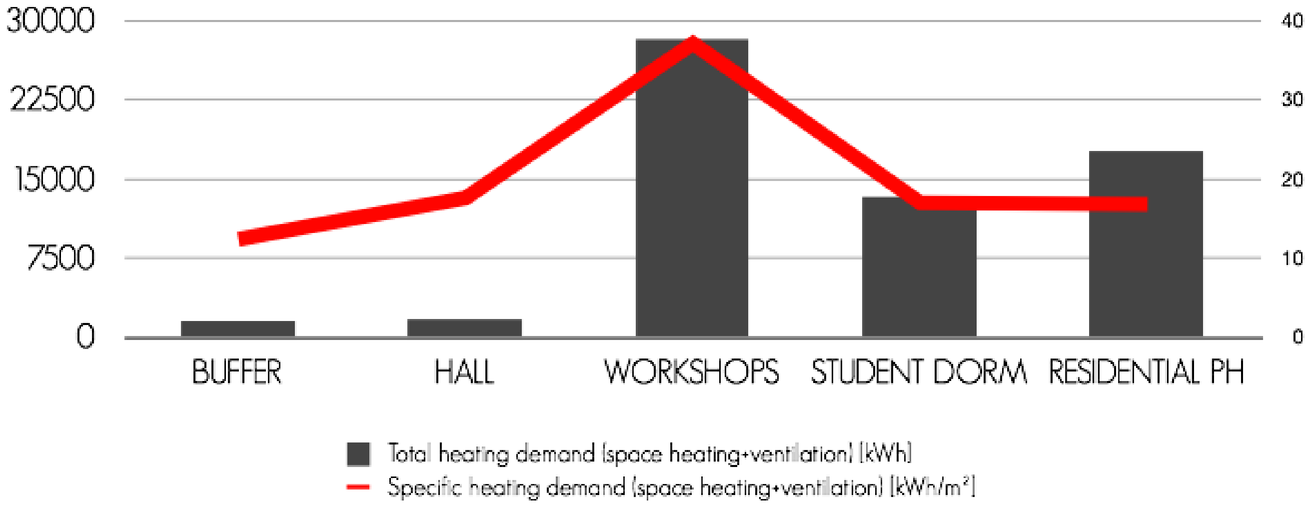


Figure 2, *energy simulation model for calculating energy demand, heated floor areas are displayed in accordance to zone colors. Here buffer areas are calculated in accordance to operational strategy. Solar contribution for buffer spaces and inter-zonal gains are included in the calculations. Buffer spaces are not included in heated BRA-area.*

This following energy budget shows the calculated heating demand, using the detailed energy simulation analogy (figure 2). The temperature of the buffer spaces is set to minimum 10C degrees and the time-of-use, and ventilation rates are optimized.



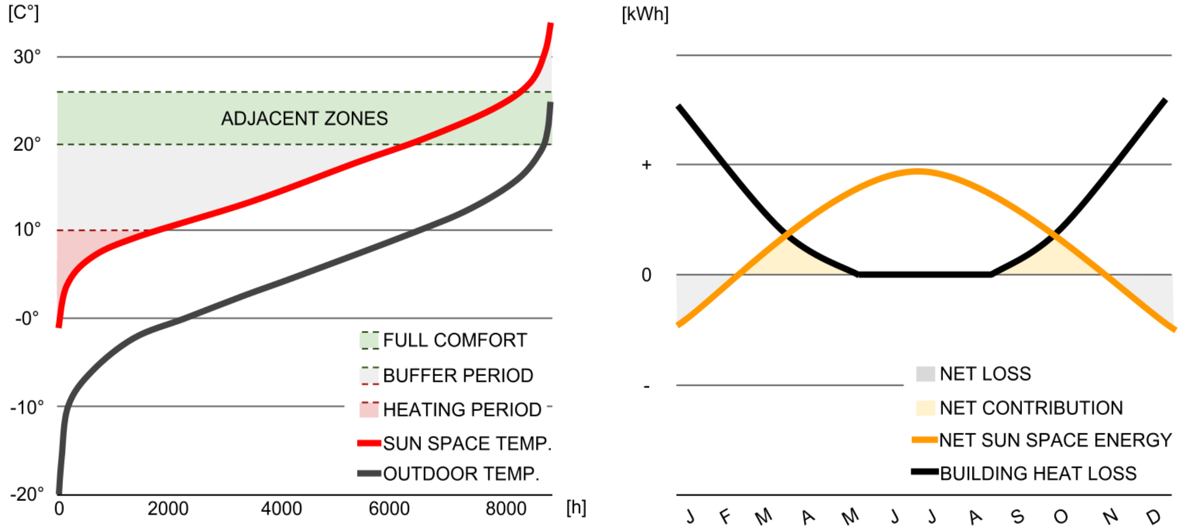


Figure 3, *thermal analysis (SIMIEN) of the sun space. The time of use can be divided into three periods of different operational characteristics. First the cold period where it acts like a buffer space with a minimum temperature of 10 C. Solar contribution period, where hot air from the sun space heats up adjacent areas. Third, the period where solar heat is too much and the space is shaded and opened up to allow for natural ventilation.*

Construction documents

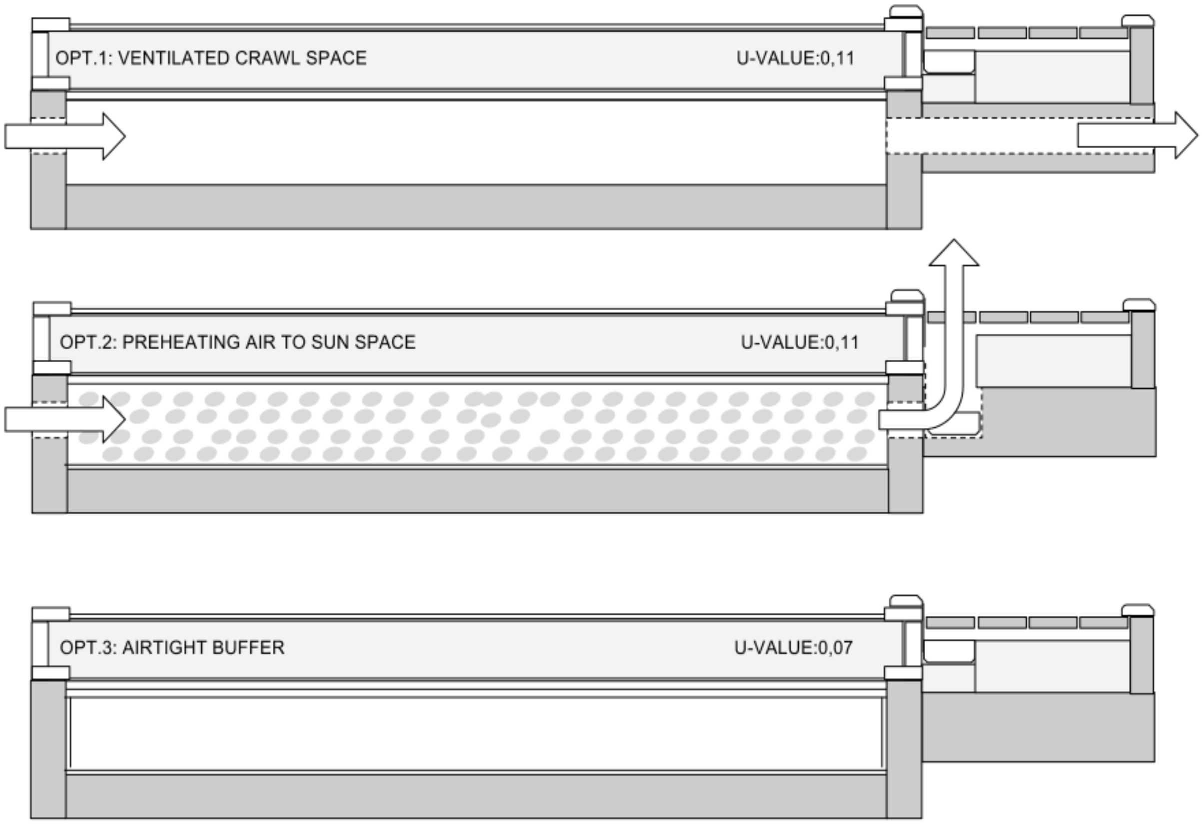


Figure 4, *Three different design concepts are discussed for the raised floor. For the energy calculations the first option, ventilated crawl space was used. Option three has the possibility, when crafted moist-proof, air-tight and non-reflective, to further reduce the heat transmission to the floor, the still air will increase the U-value, possibly to 0,07 or below, but insulation should still be part of the envelope.*

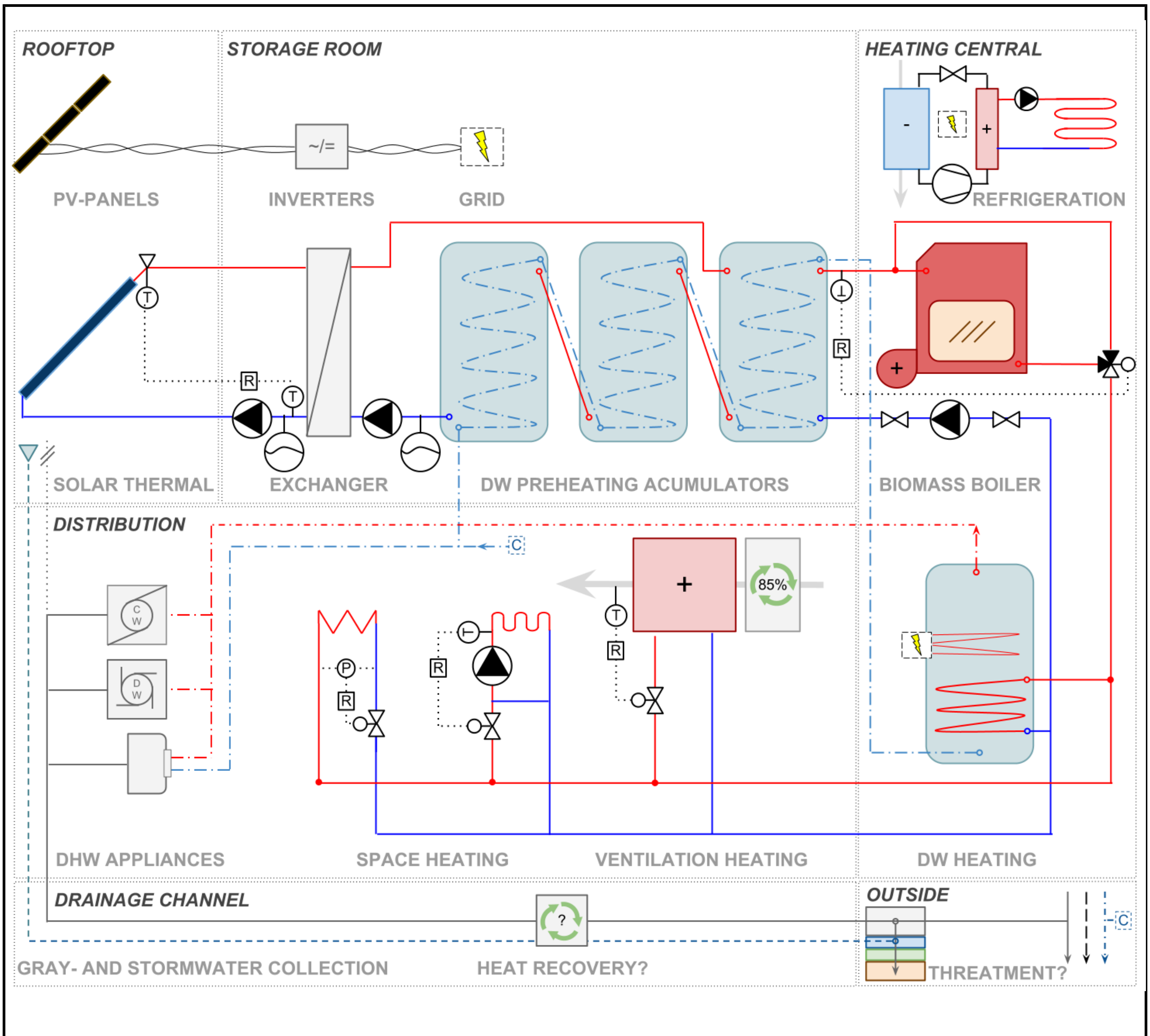


Figure 4, *integration concept of the mechanical services. The solar thermal heating system is supported by a biomass boiler. Solar thermal energy is prioritized and electricity consumption is kept to a minimum. Remaining electricity demand is covered by grid connected PV-panels.*

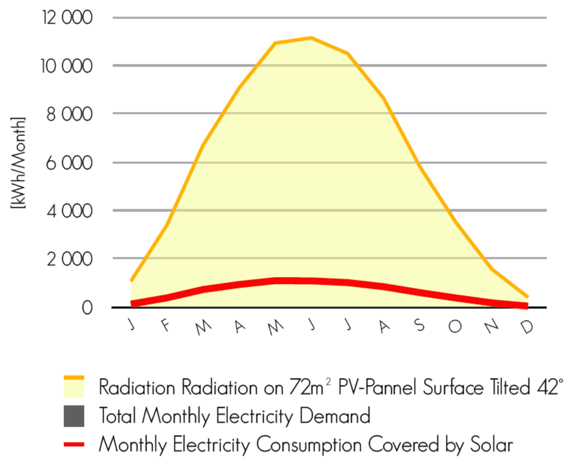


Figure 5, *solar PV-panels calculation (PVGIS). The module efficiency is 14 % and overall power rating 10 kW$_p$.*

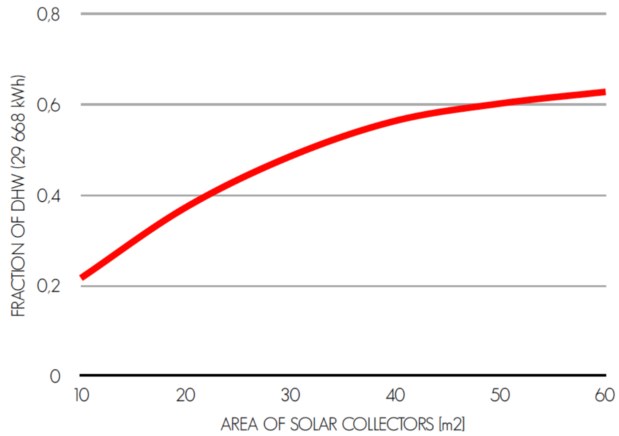


Figure 6, *solar hot water calculation (PHPP). The accumulator tank size is 3100 liter.*

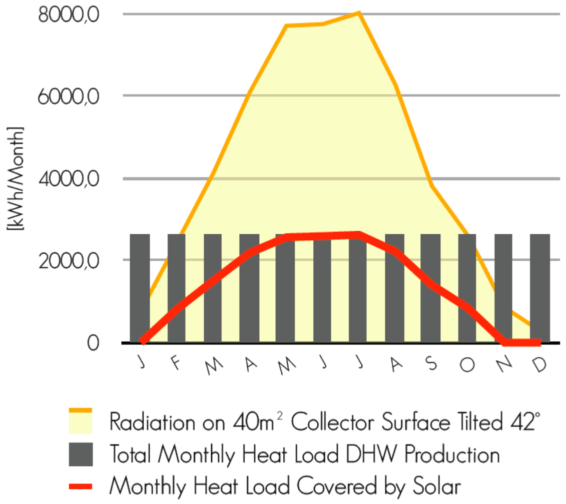


Figure 7, *solar hot water calculation with 40m² flat plate collectors (PHPP). The accumulator tank size is 3100 liter.*

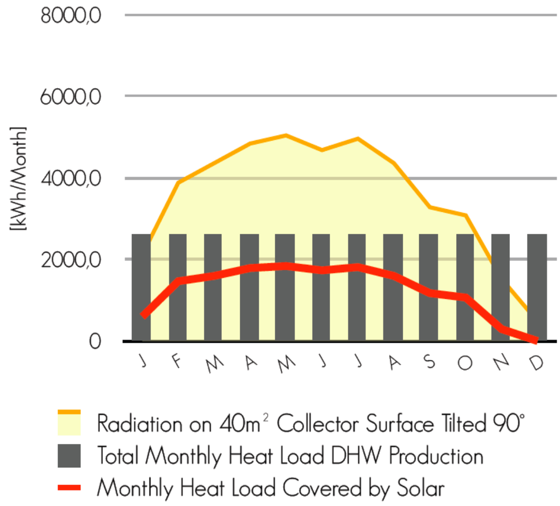
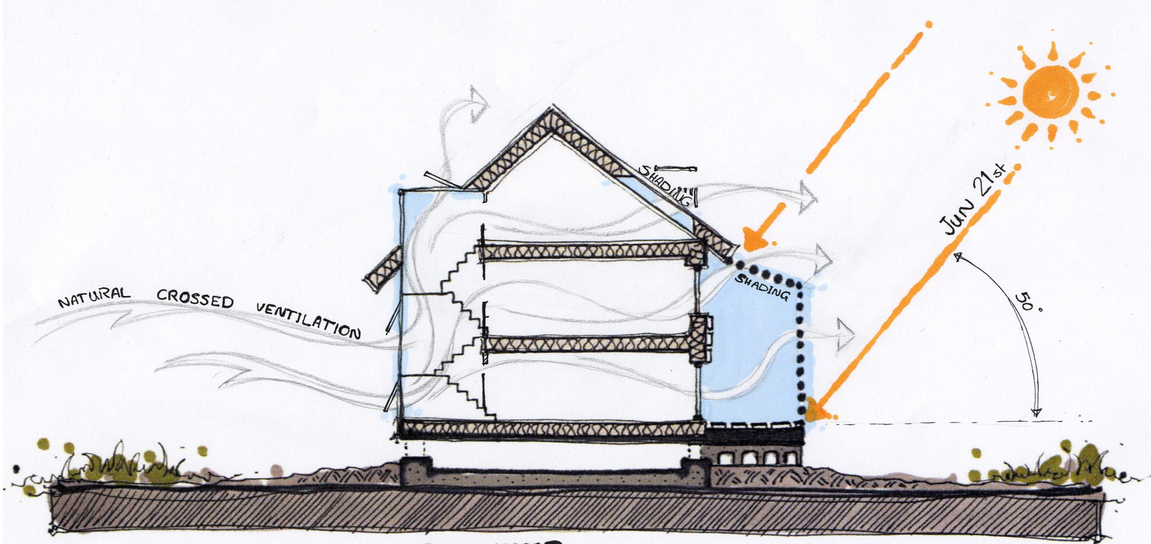
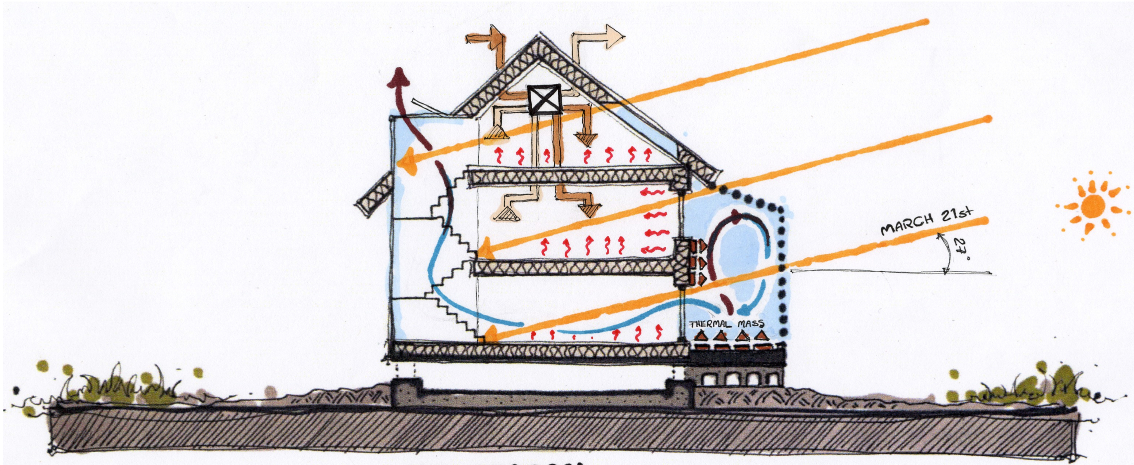


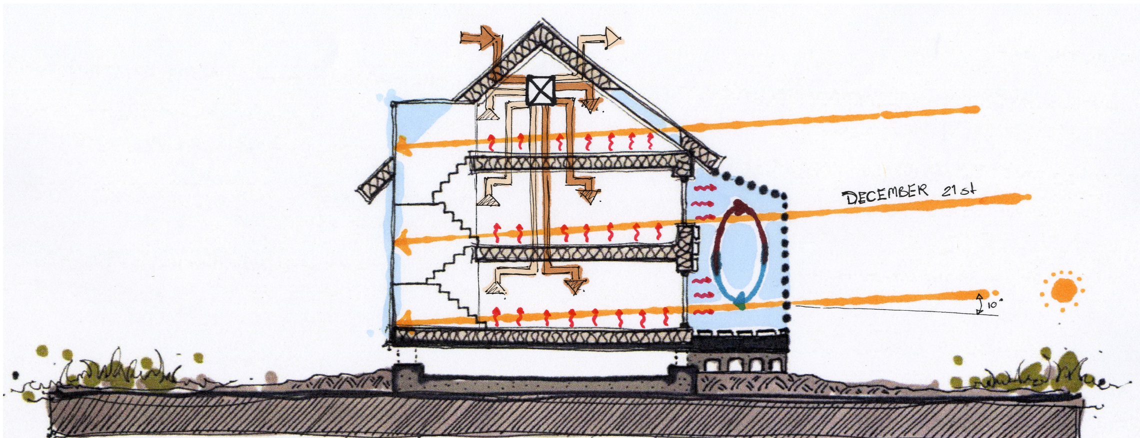
Figure 8, *solar hot water calculation with 40m² flat plate collectors (PHPP). The accumulator tank size is 3100 liter.*



SUMMER. NATURAL CROSSED VENTILATION - OUTSIDE TEMPERATUR, MAX 26°C

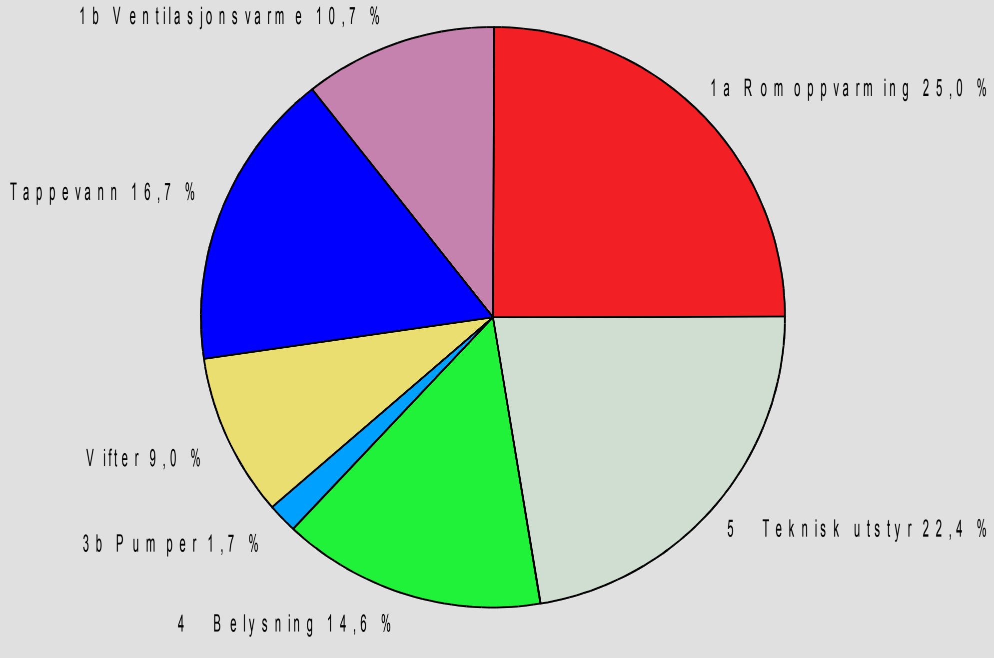


MID SEASON. STACKED VENTILATION + MECHANICAL VENTILATION



WINTER. ACTIVE HEATING + MECANICAL VENTILATION

Årlig energibudsjett



Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	44194 kWh	15,7 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	18881 kWh	6,7 kWh/m²
2 Varmtvann (tappevann)	29481 kWh	10,5 kWh/m²
3a Vifter	15927 kWh	5,7 kWh/m²
3b Pumper	2949 kWh	1,0 kWh/m²
4 Belysning	25795 kWh	9,2 kWh/m²
5 Teknisk utstyr	39704 kWh	14,1 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	176932 kWh	62,9 kWh/m²

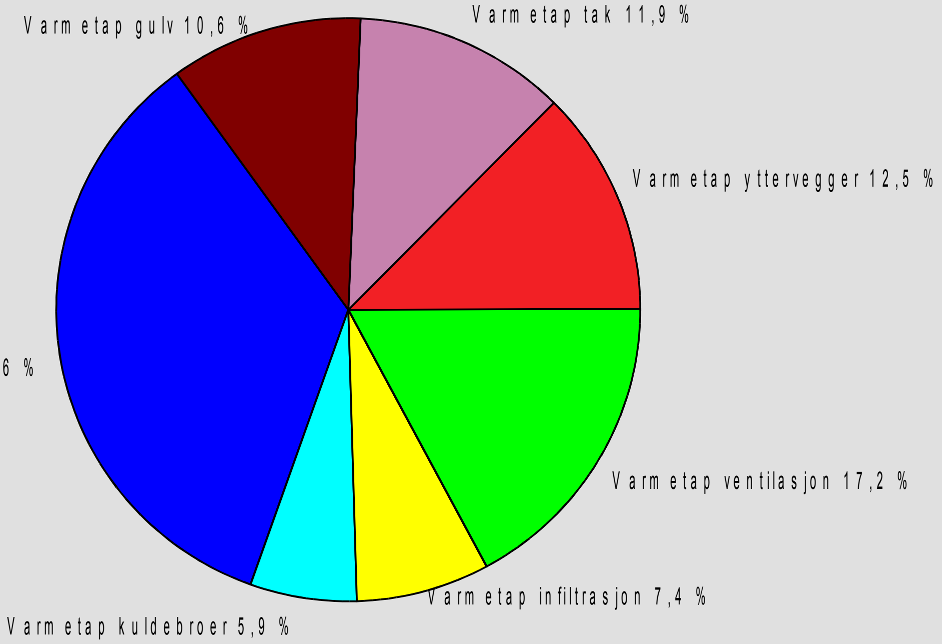
Levert energi til bygningen (beregnet)

Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	87651 kWh	31,2 kWh/m²
1b El. Varmepumpe	0 kWh	0,0 kWh/m²
1c El. solenergi	2168 kWh	0,8 kWh/m²
2 Olje	0 kWh	0,0 kWh/m²
3 Gass	0 kWh	0,0 kWh/m²
4 Fjernvarme	0 kWh	0,0 kWh/m²
5 Biobrensel	95938 kWh	34,1 kWh/m²
6. Annen ()	0 kWh	0,0 kWh/m²
Totalt levert energi, sum 1-6	185756 kWh	66,0 kWh/m²

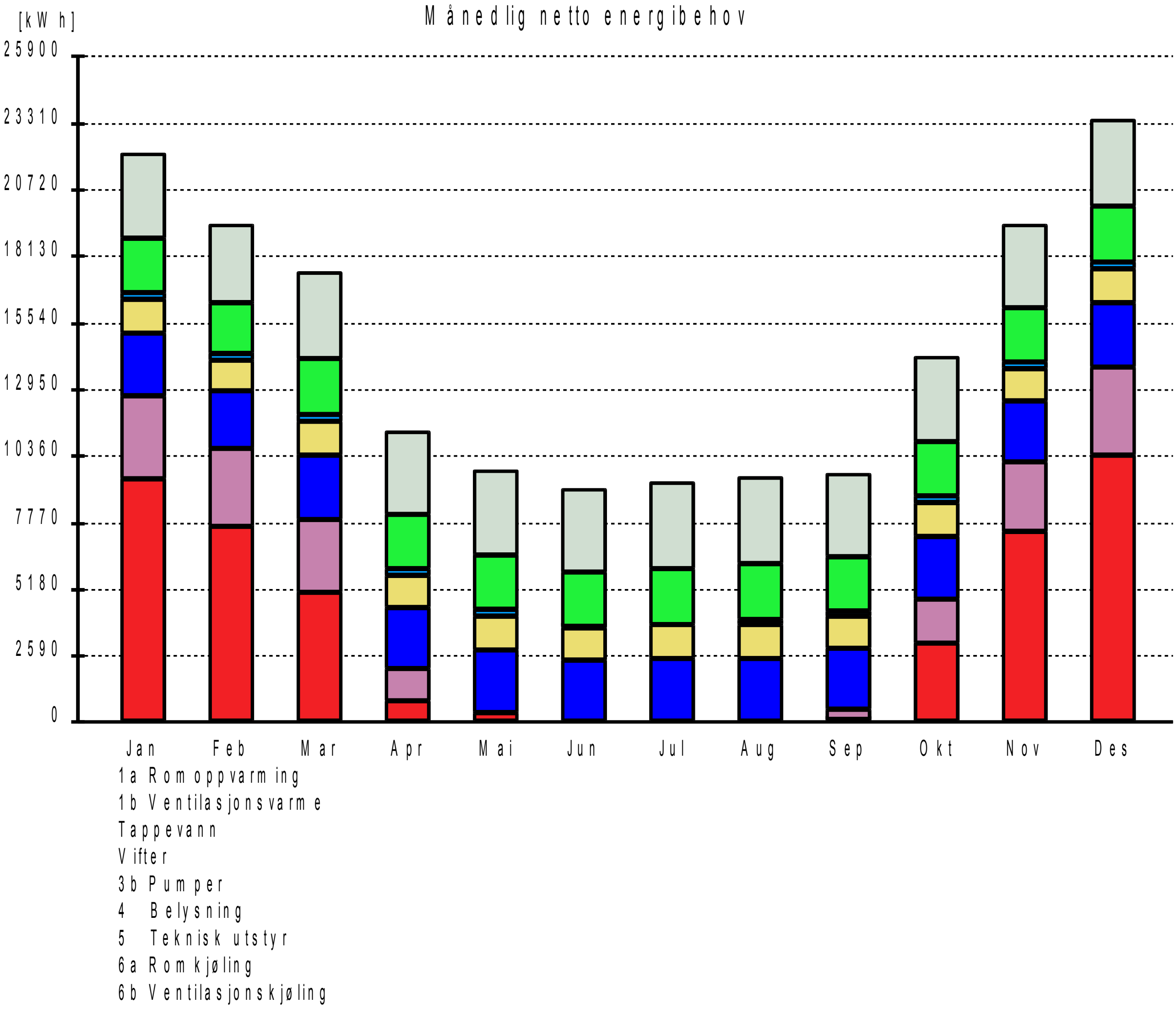
Årlige utslipp av CO2

Energivare	Utslipp	Spesifikt utslipp
1a Direkte el.	11570 kg	4,1 kg/m²
1b El. Varmepumpe	0 kg	0,0 kg/m²
1c El. solenergi	286 kg	0,1 kg/m²
2 Olje	0 kg	0,0 kg/m²
3 Gass	0 kg	0,0 kg/m²
4 Fjernvarme	0 kg	0,0 kg/m²
5 Biobrensel	1343 kg	0,5 kg/m²
6. Annen ()	0 kg	0,0 kg/m²
Totalt utslipp, sum 1-6	13199 kg	4,7 kg/m²

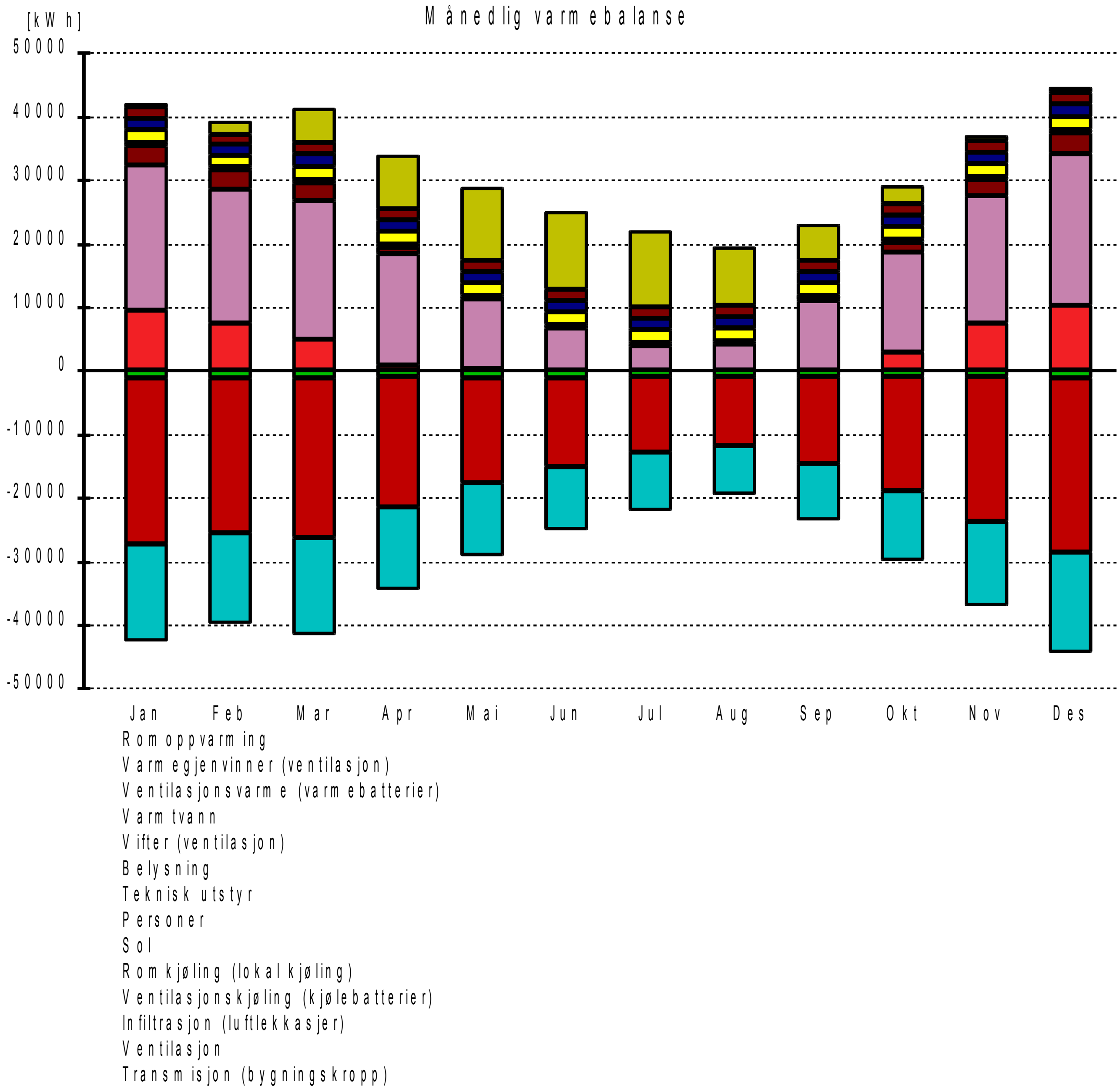
Varmetapsbudsjett (varmetapstall)



Varmetapstall yttervegger	0,06 W/m²K
Varmetapstall tak	0,06 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,05 W/m²K
Varmetapstall glass/vinduer/dører	0,18 W/m²K
Varmetapstall kuldebroer	0,03 W/m²K
Varmetapstall infiltrasjon	0,04 W/m²K
Varmetapstall ventilasjon	0,09 W/m²K
Totalt varmetapstall	0,51 W/m²K



Månedlig netto energibehov
[kWh]
25900
23310
20720
18130
15540
12950
10360
7770
5180
2590
0
Jan
Feb
Mar
Apr
Mai
Jun
Jul
Aug
Sep
Okt
Nov
Des
1a Romoppvarming
1b Ventilasjonsvarme
Tappevann
Vifter
3b Pumper
4 Belysning
5 Teknisk utstyr
6a Romkjøling
6b Ventilasjonskjøling


Månedlig varmebalanse
[kWh]
50000
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
-50000
Jan
Feb
Mar
Apr
Mai
Jun
Jul
Aug
Sep
Okt
Nov
Des
Romoppvarming
Varmegjenvinner (ventilasjon)
Ventilasjonsvarme (varmebatterier)
Varmtvann
Vifter (ventilasjon)
Belysning
Teknisk utstyr
Personer
Sol
Romkjøling (lokal kjøling)
Ventilasjonskjøling (kjølebatterier)
Infiltrasjon (luftlekkasjer)
Ventilasjon
Transmisjon (bygningskropp)

Månedlige temperaturdata (lufttemperatur)					
Måned	Midlere ute	Maks. ute	Min. ute	Maks. sone	Min. sone
Jan	-1,2 °C	8,5 °C	-19,5 °C	21,1 °C (RESIDENTIAL PH)	10,0 °C (BUFFER)
Feb	-1,7 °C	9,0 °C	-16,7 °C	22,0 °C (RESIDENTIAL PH)	10,0 °C (BUFFER)
Mar	-0,2 °C	10,7 °C	-12,0 °C	25,3 °C (RESIDENTIAL PH)	10,0 °C (BUFFER)
Apr	3,8 °C	14,2 °C	-5,6 °C	26,4 °C (RESIDENTIAL PH)	10,0 °C (HALL)
Mai	7,4 °C	20,1 °C	-2,4 °C	29,0 °C (RESIDENTIAL PH)	10,9 °C (HALL)
Jun	11,1 °C	22,7 °C	1,2 °C	30,8 °C (BUFFER)	14,7 °C (HALL)
Jul	13,8 °C	23,6 °C	4,8 °C	31,7 °C (RESIDENTIAL PH)	18,1 °C (HALL)
Aug	13,7 °C	25,0 °C	3,5 °C	32,9 °C (RESIDENTIAL PH)	15,4 °C (HALL)
Sep	10,1 °C	20,8 °C	0,6 °C	27,5 °C (BUFFER)	12,3 °C (HALL)
Okt	5,2 °C	15,5 °C	-3,3 °C	24,8 °C (RESIDENTIAL PH)	10,0 °C (HALL)
Nov	1,0 °C	10,7 °C	-11,1 °C	21,2 °C (RESIDENTIAL PH)	10,0 °C (BUFFER)
Des	-1,9 °C	9,6 °C	-17,6 °C	21,2 °C (RESIDENTIAL PH)	10,0 °C (BUFFER)

Dokumentasjon av sentrale inndata (1)		
Beskrivelse	Verdi	Dokumentasjon
Areal yttervegger [m²]:	1314	
Areal tak [m²]:	1547	
Areal gulv [m²]:	1393	
Areal vinduer og ytterdører [m²]:	507	
Oppvarmet bruksareal (BRA) [m²]:	2814	
Oppvarmet luftvolum [m³]:	9023	
U-verdi yttervegger [W/m²K]	0,14	
U-verdi tak [W/m²K]	0,11	
U-verdi gulv [W/m²K]	0,11	
U-verdi vinduer og ytterdører [W/m²K]	0,98	
Areal vinduer og dører delt på bruksareal [%]	18,0	
Normalisert kuldebroverdi [W/m²K]:	0,03	
Normalisert varmekapasitet [Wh/m²K]	49	
Lekkasjetall (n50) [1/h]:	0,69	
Temperaturvirkningsgr. varmegjenvinner [%]:	85	

Dokumentasjon av sentrale inndata (2)		
Beskrivelse	Verdi	Dokumentasjon
Estimert virkningsgrad gjenvinner justert for frostsikring [%]:	85,0	
Spesifikk vifteeffekt (SFP) [kW/m³/s]:	1,50	
Luftmengde i driftstiden [m³/hm²]	2,7	
Luftmengde utenfor driftstiden [m³/hm²]	1,1	
Systemvirkningsgrad oppvarmingsanlegg:	0,96	
Installert effekt romoppv. og varmebatt. [W/m²]:	84	
Settpunkttemperatur for romoppvarming [°C]	18,8	
Systemeffektfaktor kjøling:	2,50	
Settpunkttemperatur for romkjøling [°C]	0,0	
Installert effekt romkjøling og kjølebatt. [W/m²]:	2	
Spesifikk pumpeeffekt romoppvarming [kW/(l/s)]:	0,50	
Spesifikk pumpeeffekt romkjøling [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt varmebatteri [kW/(l/s)]:	0,50	
Spesifikk pumpeeffekt kjølebatteri [kW/(l/s)]:	0,60	
Driftstid oppvarming (timer)	14,7	

Dokumentasjon av sentrale inndata (3)		
Beskrivelse	Verdi	Dokumentasjon
Driftstid kjøling (timer)	0,0	
Driftstid ventilasjon (timer)	13,5	
Driftstid belysning (timer)	16,0	
Driftstid utstyr (timer)	13,4	
Oppholdstid personer (timer)	13,0	
Effektbehov belysning i driftstiden [W/m²]	1,54	
Varmetilskudd belysning i driftstiden [W/m²]	1,54	
Effektbehov utstyr i driftstiden [W/m²]	2,76	
Varmetilskudd utstyr i driftstiden [W/m²]	1,66	
Effektbehov varmtvann på driftsdager [W/m²]	1,26	
Varmetilskudd varmtvann i driftstiden [W/m²]	0,00	
Varmetilskudd personer i oppholdstiden [W/m²]	1,92	
Total solfaktor for vindu og solskjerming:	0,26	
Gjennomsnittlig karmfaktor vinduer:	0,17	
Solskjermingsfaktor horisont/bygningsutspring:	0,91	

Inndata energiforsyning	
Beskrivelse	Verdi
1a Direkte el.	System virkningsgrad: 0,90 Kjølefaktor: 2,50 Energipris: 0,80 kr/kWh CO2-utslipp: 132 g/kWh Andel romoppvarming: 0,0% Andel oppv, tappevann: 10,0% Andel varmebatteri: 0,0 % Andel kjølebatteri: 100,0 % Andel romkjøling: 100,0 % Andel el, spesifikt: 100,0 %
5 Biobrensel	System virkningsgrad: 0,73 Kjølefaktor: 2,50 Energipris: 0,65 kr/kWh CO2-utslipp: 14 g/kWh Andel romoppvarming: 90,0% Andel oppv, tappevann: 45,0% Andel varmebatteri: 90,0 % Andel kjølebatteri: 0,0 % Andel romkjøling: 0,0 % Andel el, spesifikt: 0,0 %
1c El. solenergi	System virkningsgrad: 9,03 Kjølefaktor: 2,50 Energipris: 0,80 kr/kWh CO2-utslipp: 132 g/kWh Andel romoppvarming: 10,0% Andel oppv, tappevann: 45,0% Andel varmebatteri: 10,0 % Andel kjølebatteri: 0,0 % Andel romkjøling: 0,0 % Andel el, spesifikt: 0,0 %