Inotherm^{+}; A next generation highly efficient thermal energy system for energy positive buildings

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Abstract. The thermal energy system in the energy positive Powerhouse Brattørkaia[*] is one of the worlds most efficient ones. It has been awarded with the NOVAP[†] heat pump award in 2020 and the EHPA[‡] heat pump award in the DecarBuilding category in 2021. This paper describes- and documents the estimated performance of a next generation highly efficient thermal energy system for energy positive buildings. The system is named *Inotherm*$^{+}$, and will be implemented in several future projects. The system is designed to efficiently cover 100 % of the buildings domestic hot water, heating and cooling demand. The first pilot project with this solution, *Lindesnes Helsehus*, is currently under construction, and simulations show about 30-50 % improvement of the SCOP factor compared to the original system implemented in Powerhouse Brattørkaia. The new design combines a thermal battery, a thermal storage system for domestic hot water, a low exergy heating and cooling system [1], a geothermal energy system, and an industrial R717 heat pump equipped with a desuperheater.

1 Introduction

Lindesnes Municipality is planning the construction of 72 care homes, 48 short-term places for treatment and rehabilitation, three day-activity centers and a base for healthcare personnel. Co-located with the care homes, a new health center is planned for the municipality's residents. In addition, the solution includes a smart charging infrastructure for 90 EV's providing home-based services. The project will be built at Orelunden, Søren Jaabæks vei 60 in Mandal, Norway.

[*] https://virtualpavilion.co/powerhouse-brattorkaia
[†] Norwegian Heat Pump Association
[‡] European Heat Pump Association

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Fig. 1. Illustration, Lindesnes Helsehus, Mandal, Norway. Source: Bølgeblikk Architects

The main target related to energy and emissions is to achieve ZEB-O÷EQ+20%M defined by the research center for zero emission buildings (ZEB). This means that the building's renewable energy production throughout its life cycle must compensate for the greenhouse gas emissions from:

- Operation of the building, but not including the energy that goes into user equipment.
- 20% of the building materials.

To achieve the target, the building must produce more energy than it uses implying an energy performance that is exceptional for health buildings worldwide This ambition has triggered a large degree of innovation in the project. This paper focuses on the thermal energy system developed for the project.

2 Inotherm⁺, a next generation highly efficient thermal energy system for energy positive buildings

The thermal energy system is based on the innovative thermal system developed by Skanska for the plus energy building Powerhouse Brattørkaia and BI's new head office in Trondheim. The system was awarded the heat pump prize by the Norwegian Heat Pump Association, 10 March. 2020, and the international heat pump award in the "DecarbBuilding" category in 2021. The performance of the ammonia heat pump in this central unit is particularly high [2].

Nevertheless, a significant improvement potential has been identified. One of the weaknesses of the Powerhouse/BI system is that the heat pump must deliver a high flow temperature due to radiator-based heating system in the BI building, which reduces the efficiency. Another and more important disadvantage is that the heat pump, as it is integrated into the system, is not able to cover the entire domestic hot water demand in the buildings. It contributes with some base load heating, but most of the domestic hot water heating is done by direct electricity.

Inotherm^{+} is a result of the effort in developing a more flexible, energy-efficient, impact-limiting, cost-effective solution, which, regardless of the distribution between the project's heating needs and domestic hot water needs, is able to cover both with a higher degree of efficiency than is possible to achieve even with the best alternative solutions in the market today. A conceptual sketch for the solution is shown in Figure 2. Below follows a more detailed description of the solution and its most important components and functions.

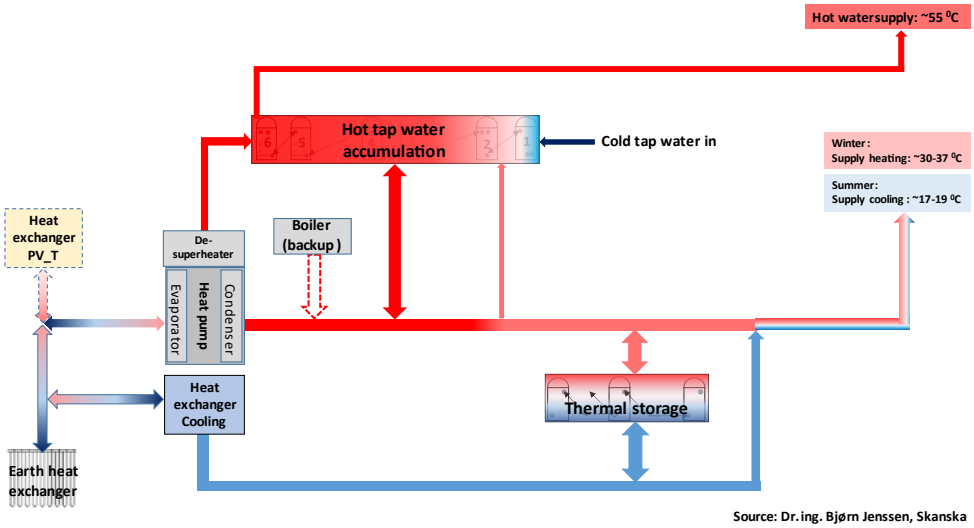


Fig. 2. *Lindesnes Helsehus*, concept solution, *Inotherm*+

2.1 The technical solution

Based on the concept shown above, the aim is to develop an optimized technical solution. A more detailed system sketch for the most central components is shown in Figure 3 below.

A complete, detailed solution that also includes all underlying systems (underfloor heating and cooling, ventilation heating and cooling, system for exterior snow melting of entrances etc.) will be designed in the last part of the detailed project design phase.

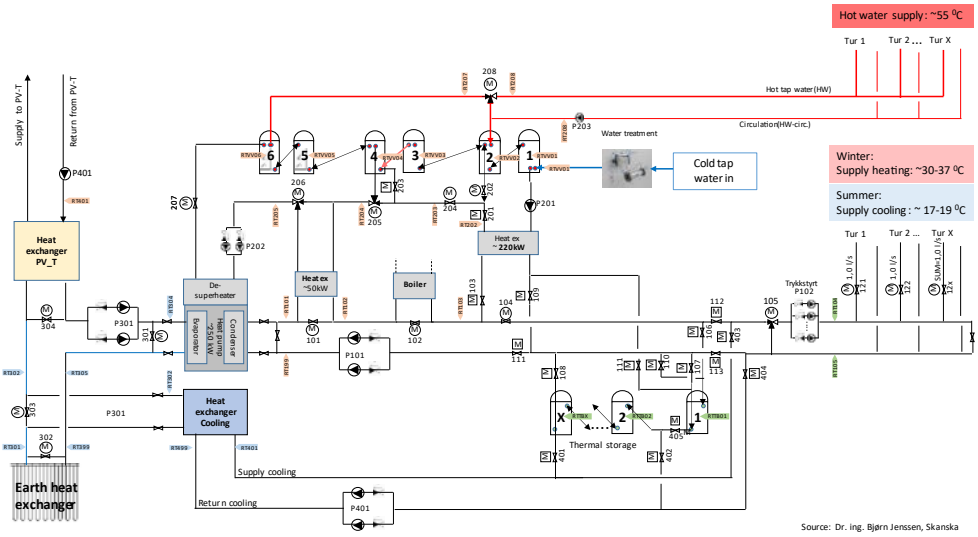


Fig. 3. *Lindesnes Helsehus*, technical solution, *Inotherm*+

2.2 The heat pump

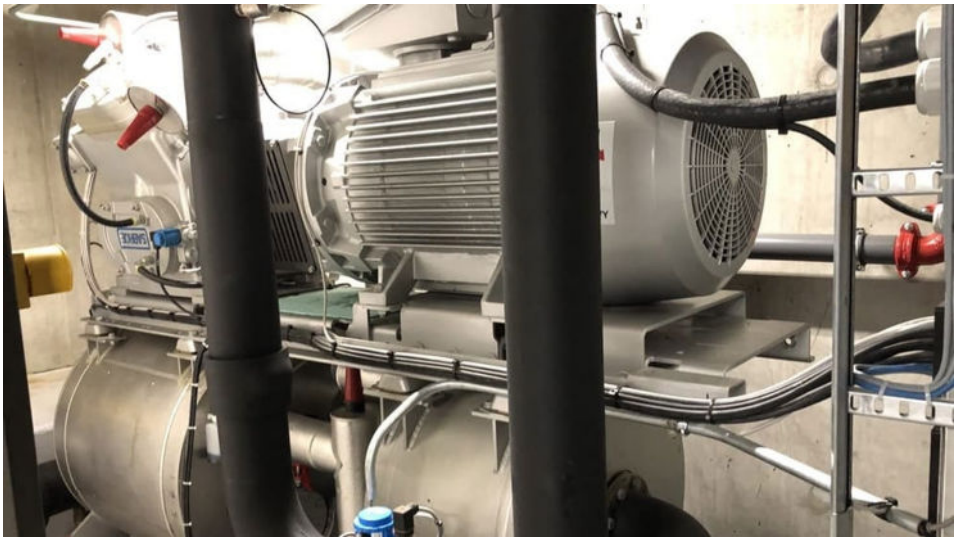


Fig. 4. The Sabroe SMC 104 S heat pump in Powerhouse Brattørkaia, Trondheim, Norway. Photo: Norwegian heat pump association

One of the success criteria for the award-winning thermal energy solution in Powerhouse Brattørkaia was that it rejected the traditional way of designing the heat pump systems combining a CO_2 tap water heat pump and a propane heat pump for space heating in each building. Instead of four traditional, commercial heat pumps, it was decided to use the resources on a high-quality industrial heat pump and adapt the system solution around this. After analyzing a number of machines, the selected industrial heat pump Sabroe SMC 104 S stood out as the one with the best performance and quality. It is an extremely robust machine, with which there are rarely/never operational problems. Assuming regular service and maintenance, it will be able to last its lifetime (60 years +). It has four 100 mm cylinders, which can be regulated modularly between 1800 and 500 RPM. At 1800 RPM it typically produces around 250 kW, and at 500 RPM it produces about 70 kW.

Estimated heating needs for Lindesnes Helsehus are, thanks to the sum of all energy saving measures, at the same level as Powerhouse Brattørkaia and BI, but the need for domestic hot water is significantly higher. Based on the good operating experience of the Sabroe SMC 104 S, the same heat pump will be used, but with one difference: The heat pump for Lindesnes Helsehus will be equipped with a desuperheater.

2.3 The desuperheater

Normally, the heat pump's efficiency is significantly reduced the higher the supply temperature. Given a brine temperature (temperature from the energy wells) of 5 ^{0}C, a supply temperature of 50 ^{0}C and a heat output of 125 kW, the heat pump will give a COP of ~4.49. If the flow temperature is reduced to 35 ^{0}C, it will give a COP of ~6.32 with the same brine temperature and the same delivered power.

However, the desuperheater, a heat exchanger placed after the compressor in the heat pump, makes it possible to transfer between 10% and 20% of the heat pump's output directly to the domestic hot water accumulator as high-temperature heat without the efficiency (SCOP)

being significantly reduced. This means that the heat pump can deliver 35 ^{0}C to the heating system in the building with very high COP, while the desuperheater heats the tap water to 60 ^{0}C or more.

Although there are many examples of the use of desuperheaters, not all installations are successful. The quality of the heat pump and associated components, as well as the control and management of quantity and temperature above the desuperheater, are essential for good performance and stable operation.

The proposed design simplifies management as the desuperheater is allowed to supply heat directly from the gas to the tap water, without an intermediary in the form of a separate closed circuit and exchanger. This will provide better performance, lower energy and power requirements, fewer components and simplified control.

2.4 The earth heat exchanger

The earth heat exchanger is the most important source of renewable heating and cooling, and at the same time constitutes the thermal seasonal storage in the project. While the thermal storage tank system is designed to handle variations throughout the day, the earth heat exchanger will store and release energy over weeks, months and years.

Initially, 27 energy wells with an average depth of ~200 meters are planned. This will be adjusted in the detailed design phase using detailed simulations of the building, energy system and thermal response from the energy wells.

Overall, the *Inotherm*$^+$ solution provides great flexibility to be able to control the extraction of heat and cooling from the well system optimally. This increases efficiency, improves the utilization of renewable heating and cooling, which in turn reduces energy and power consumption and associated emissions and operating costs.

One of the keys to achieving optimal performance for the well system is a good balance. Throughout the year, the aim is to extract the same amount of heat in the winter as that supplied by heat in the summer via the cooling system.

The system gives the opportunity to control the extraction of heating and cooling. The excess heat from the cooling system is used as a source for the heat pump, and/or the earth heat exchanger. However, detailed simulations of the building and thermal energy system show that this is not enough to achieve balance over the year. The extraction of heat is calculated to be between 7 and 8 times as high as what is fed back in the summer via the cooling system. This may cool the earth heat exchanger over time, making it unable to cover the heating demand after some years of operation.

The solution to this is the correct utilization of an innovative technology that has been known for many years, but with which there are very few pilot projects, namely Hybrid PV panels (PV-T).

2.5 The hybrid PV's (PV-T)

Hybrid solar cells (PV-T) are solar cells with an active cooling system. This potentially provides two benefits:

1. Cooling the solar cells improves electricity production since the solar cells produce at their highest efficiency when the temperature is low.
2. The heat from the cooling system can be used for heating.

The panels are able to deliver around three times as much heat as solar power. However, this requires relatively low temperature on the cooling (brine) circuit.
This goes hand in hand with the *Inotherm*$^{+}$ solution, as it is very well suited to utilize this type of moderate temperature source. This is done by connecting the PV-T plant to the brine circuit, providing an additional source for the heat pump.
The hybrid solar cells make up around ¼ of the total solar system that is planned to be installed.

2.6 The LowEx system

Low supply temperature is crucial for energy and power load for the heat pump. The data runs show that the COP factor increases by 30% when the flow temperature is lowered from 50 ^{0}C to 35 ^{0}C. This means that the heat pump's electricity consumption is reduced by 30% thanks to this temperature reduction. Designing the system for low temperature operation is the core of the LowEx project.

The traditional LowEx solution is based on cooling/cooling via an underfloor heating system with a relatively high supply cooling temperature, typically around 17-19 ^{0}C. Where underfloor heating is installed, temperature sensors are installed in the concrete to control the opening of underfloor heating loops so that cooling of the concrete slabs is achieved. The building then acts as a thermal solar collector, and excess heat is primarily used as a source for the heat pump to heat tap water, and secondarily used to charge the energy wells.

Underfloor heating has a number of advantages, but also some disadvantages. Among other things, significant additional costs vs. the use of radiators or heating via ventilation air. In addition, embedding underfloor heating pipes normally results in increased material use due to the need for extra cast, and associated increased greenhouse gas emissions.

The design-team for Lindesnes Helsehus concluded that the most optimal solution is a combination of air heating, ventilation cooling, underfloor heating and cooling. This integrates several innovative technologies into one flexible, reliable and robust solution.

In cooling mode, both the floor cooling and the combined exchangers in the ventilation units will provide heat for hot tap water production via the heat pump. Thus, the system has the same major advantage as the original Low-Ex system.
The switching between cooling mode and heating mode is done according to the principles developed in the LowEx project. The implementation is described in a separate note [3]. The central control consists of three operating modes:

1. Heating
2. Passive (no heating og cooling required)
3. Cooling

The criterion for choosing the operating mode is basically based on a weighted daily average temperature for the next two days. This is based on forecasts from yr. If you choose to use forecast management, it is basically recommended that the daily mean temperature of the nearest day is weighted 70% day one, and 30% day 2, as follows:

$$T_{d\ weighted} = 0{,}7 \cdot T_{d\ (0-24)} + 0{,}3 \cdot T_{d\ (24-48)} \quad (1)$$

Based on simulations, the proposed criteria for the operation of Lindesnes Helsehus is:

1. Operating mode 1: The weighted average daily temperature for the next two days is below 9 ^{0}C
2. Operating mode 2 (passive): Weighted average daily temperature for the next two days is between 9 and 13 ^{0}C
3. Operating mode 3 (cooling): Weighted 24-hour average temperature over the next 24 hours is above 13 ^{0}C

If needed, the set points will be adjusted during trial operation, and the results will provide useful experience for subsequent projects.

2.7 Thermal storage

The thermal storage consists of accumulator tanks with a total of 30,000 liters of water. The storage system is able to store ice water down to 0 ^{0}C.
The storage provides good working conditions for the heat pump. The storage will naturally smooth out short-term variations, so that the heat pump can work smoothly and calmly, without large temperature fluctuations. This also avoids frequent start/stop and instability in the regulation of heat pump operation. It eliminates the potential disadvantage of the heat pump being "oversized", which is often used as an argument for using several small, parallel-connected heat pumps (with a lower efficiency) in the system.

The thermal storage, together with the heat pump, will supply a low-temperature heating system with a maximum flow temperature of around 35 ^{0}C.

The storage makes it possible to cover the entire need for tap water heating, without the use of an additional heat pump. During the short periods the heat pump supplies heat only to tap water, the thermal storage will supply the building with room and ventilation heat.

The thermal storage also increases the maximum power capacity of the system. For short periods under design winter conditions, the heat pump alone will not be able to deliver enough quantity/power to cover the demand, and the thermal storage comes to rescue, providing the necessary additional heat.

2.8 Domestic hot water heating

Heat pump systems for tap water heating are today solved in a myriad of different ways. In recent years, CO_2 heat pumps have become increasingly common. A particular challenge with CO_2 heat pump systems is that they are dependent on a low return to the gas cooler in order to achieve high efficiency. If the return temperature is too high, the heat pump will eventually stop, although a significant temperature increase is still needed to ensure a high enough water temperature. High performance of CO_2 heat pumps thus requires very good planning and management of the circulation, and where circulated water is returned in the accumulation system in order to maintain stratification and avoid mixing.

Another disadvantage with CO_2 heat pumps is the lack of ability in utilizing high brine temperatures. If you "risk" a high brine temperature, the system must be able to shunt the temperature down to a level that is acceptable for the heat pump, with lack of exergy and

efficiency as a result. This means poorer utilization of the heat source, increased complexity for the plant and a greater risk of operational problems.

Ammonia heat pumps, by comparison, are good at both utilizing high brine temperatures, and handling high return temperature on the hot side. The solution is therefore particularly well suited to cover circulation losses. It provides high performance even when the incoming water temperature to the condenser becomes high as a result of circulation.

The system is designed for three operating modes; Normal winter operation, top charging winter and top charging summer.

2.9 Flexibility for expansion of the thermal system

The thermal system will be arranged so that it can be easily connected in case of any expansion of the project, or alternatively any new projects in the neighborhood. This could contribute to even better utilization of the renewable sources on site, with further reductions in energy and power consumption as a result [4]. The measure consists of setting aside space, arranging and installing the necessary connectors for easy future connection.

3 Methodology

3.1 Tools

There are mainly two tools that have been used to simulate the energy performance of the proposed design as detailed and realistically as possible:

1. The building simulation tool SIMIEN7 version 7.031. This is the precursor to SIMIEN PRO, a completely new and more advanced version of SIMIEN. SIMIEN 7 is, in contrast to SIMIEN 6, based on the Norwegian standard SN-NSPEK 3031:2020. This means, for example, that it has more detailed demand profiles for various building categories, which provides a better and more realistic dynamic load calculation for tap water, lighting, technical equipment and personal load. Unlike previous versions, SIMIEN7 is also well suited to simulating advanced operation with ventilation heating, high-temperature cooling and low-temperature heating via building structures, pipe systems with heat loss in different zones, detailed simulation of heat pump system performance and more. The building model is divided into 83 calculation zones. The zones in the building model are classified within two different building categories; Office buildings, which include typical day healthcare services, and nursing homes, which include housing and associated service functions. The nursing home part comprises approx. 55% of the total usable area, while the office part makes up approx. 45%.

2. Calculation tool in excel developed for detailed simulation of the Inotherm+ solution, as well as load management of electrical power and detailed calculation of the performance of the various systems and components, including electromobility. Net and gross energy demand from the SIMIEN model is used as input. The reason why we have programmed this in excel is that there are no tools that are able to calculate this in a simple way. In practice, one must program a logical control code for charging and extracting energy from the thermal storage and tank system for hot tap water, switching between different modes of operation, including space heating, tap water and cooling, calculation of the correct brine temperature for the heat pump, calculation of the correct efficiency for the heat pump in the applicable

time step, management of loads, management of charging of electric fleet with service vehicles and more.

Note that the complete model includes both the building and associated technical systems, and a charging facility for the municipality's 90 service vehicles.

3.2 The reference model

In order to evaluate the design towards a comparable traditional solution, a reference simulation model has been developed using the same tools, methodology and geometric input. However, insulation levels and technical qualities in the reference model has been reduced to the level needed to satisfy the Norwegian building code minimum requirements (corresponding to Energy label C). For example, the heat pump is replaced by an electric boiler in the reference model, and the average external wall U-value is reduced from 0,17 to 0,22 $W/m^2 \cdot K$, efficiency of ventilation heat recovery is reduced from 85 to 74 % etc.

3.3 Simulations

The method that has been used can be briefly described as follows:

1. Geometry and known technical data is fed into the SIMIEN model.
2. Winter simulation is carried out. The ventilation system, heating system, temperatures, outdoor compensation curves etc. are adjusted until the calculations show satisfactory comfort in all 87 calculation zones.
3. Summer simulation is carried out. Cooling, ventilation, and solar shading are adjusted until the calculations show satisfactory comfort in all zones under design summer conditions.
4. Annual simulation is carried out.
5. The results from the annual simulations are loaded into the excel spreadsheet tool for simulation of the technical systems, including EV charging.
6. The size of the thermal storage and hot tap water storage is optimized through simulations so that no peak load coverage by the electrical boiler is needed
7. The design and control algorithms are tuned to achieve as good results as possible.
8. Steps 1-7 are repeated until all errors have been corrected and all results are satisfactory.
9. The results are analysed, summarized, and presented (tables and graphs).

4 Results

4.1 Energy

The resulting specific energy demand and production from the yearly simulation of the building models with local climate are shown in Figure 5 below. Energy label C represent the reference model. The energy label A results are calculated as by multiplying the energy label C results by a factor of 0,6, according to the difference in minimum requirements between label A and C.

While the annual need for delivered energy for the TEK 17 reference is calculated at 3,997,164 kWh, the proposed design is estimated to provide a surplus of 24,560 kWh, see Table 1. This gives a total energy result of 4,021,724 kWh electricity per year.

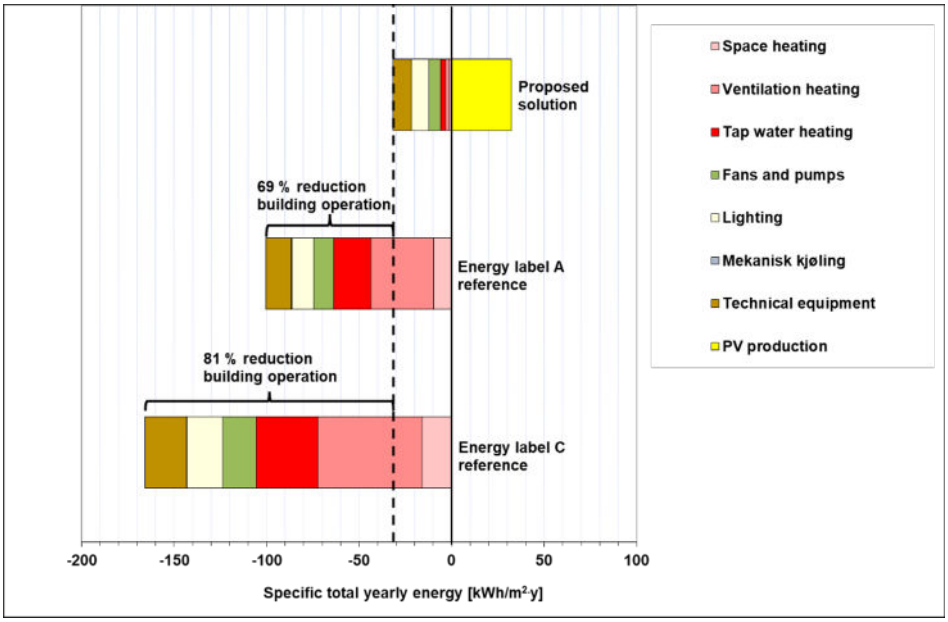


Fig. 5. Lindesnes Helsehus, simulated specific energy for the minimum reference (Energy label C) and the proposed solution, compared with calculated energy for a typical energy label A alternative.

Table 1. Lindesnes Helsehus, total simulated yearly energy

NOHL, TOTALT YEARLY ENERGY BUDGET						
Energy post		Net demand [kWh/year]	Distribution- and regulation efficiency [n]	Gross demand [kWh/year]	System	Delivered energy [kWh/year]
1a	Space heating	53 064	0,88	60 480	Heat pump and thermal storage	8 757
					Electric boiler	0
					Direct electric heating	20 742
1b	Ventilation heating	292 435	0,89	328 981	Heat pump and thermal storage	47 633
					Spisslast elkjel	0
2	Tap water heating	261 663	0,80	327 707	Varmepumpe og termisk batteri	65 729
					Direct electric peak load	0
3a	Fans	136 879	1,00	136 879	Direct electric	136 879
3b	Pumps	16 748	1,00	16 748	Direct electric	16 748
4	Lighting	228 132	1,00	228 132	Direct electric	228 132
5	Technical equipment	234 246	1,00	234 246	Direct electric	234 246
6a	Slab cooling (Low-ex free cooling)	27 325	1,00	27 325	Included in "pumps"	
6b	Ventilation cooling (Low Ex free cooling via combined exchangers)	28 969	1,00	28 969	Included in "pumps"	
6c	Prosess cooling (Low Ex free cooling via fancoils)	17 520	1,00	17 520	Included in "pumps"	
SUM [kWh/m2/år]		**1 296 981**		**1 406 987**		**758 867**
7	**Total PV production**					**-783 427**
	Solar power to building operation					**-340 592**
	Surplus solar power for EV charging or export					**-442 835**
Totalt power consumption (negative result = plus energy building) [kWh//year]						**-24 560**

Table 2. Lindesnes Helsehus, total simulated specific yearly energy

NOHL, TOTALT YEARLY ENERGY BUDGET						
Energy post		Net demand [kWh/year]	Distribution- and regulation efficiency [n]	Gross demand [kWh/year]	System	Delivered energy [kWh/year]
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4.2 *Inotherm*$^{+}$

Based on the tools and simulation methodology described in section 5 above, this section focuses on detailed simulation results for *Inotherm*$^{+}$ system.

4.2.1 The heating season

Figure 6 shows that the demand during the coldest periods in winter is higher than the heat pump capacity. Figure 7 shows how the thermal storage solves this.

By default, the state of charge of the thermal storage is close to 100 %. But when demand exceeds heat pump capacity, the thermal storage contributes to cover the demand. The brown curve shows that the maximum contribution from the thermal storage is around 80 kW this cold week. When demand falls back below the capacity of the heat pump, the thermal storage is automatically charged again (the brown curve below zero).

The same logic applies for the storage of hot tap water, see Figure 8. The results also shows that heat from the desuperheater is not able to cover the demand. Top charging is therefore triggered one to three times per day (the higher the space and ventilation heating demand, the less top charging is needed).

The COP is calculated each hour by cross interpolating between pre-calculated values as a function of heating power, supply temperature and temperature from the earth heat exchanger and cooling system (brine temperature). The temperature from the earth heat exchanger is assumed according to Table 3, and the brine temperature is calculated takin into account the heat received from the cooling system and hybrid PV-T panels.
Figure 9 shows the calculated brine temperature and COP during top charging and normal low temperature heating operation respectively for the actual week.

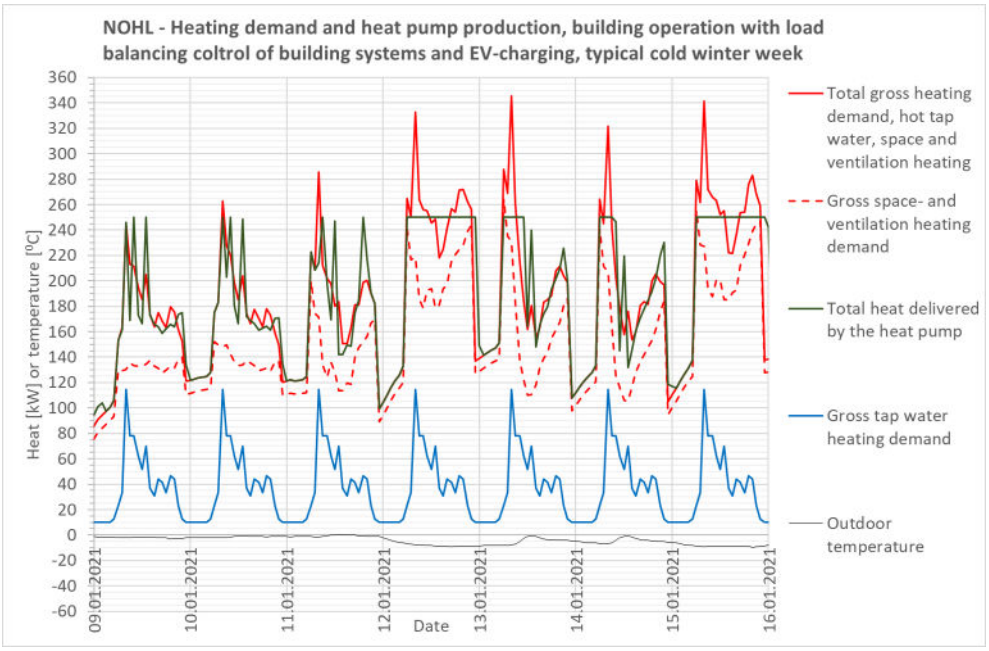


Fig. 6. Lindesnes Helsehus, heating demand and heat pump operation during a typical cold winter week.

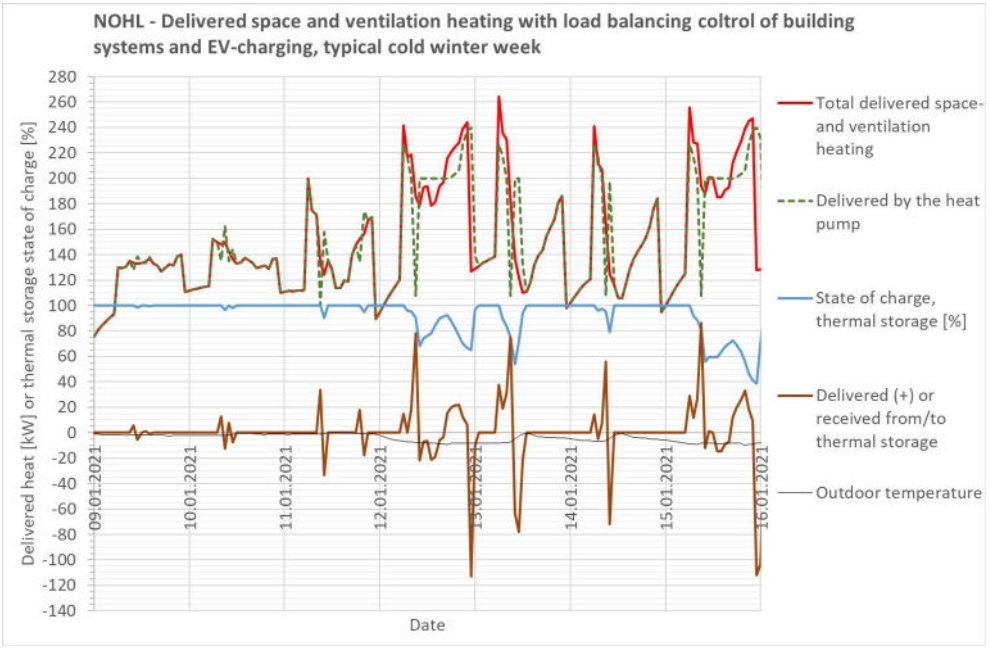


Fig. 7. Lindesnes Helsehus, production, delivery and storage of heat for space- and ventilation heating during a cold winter week.

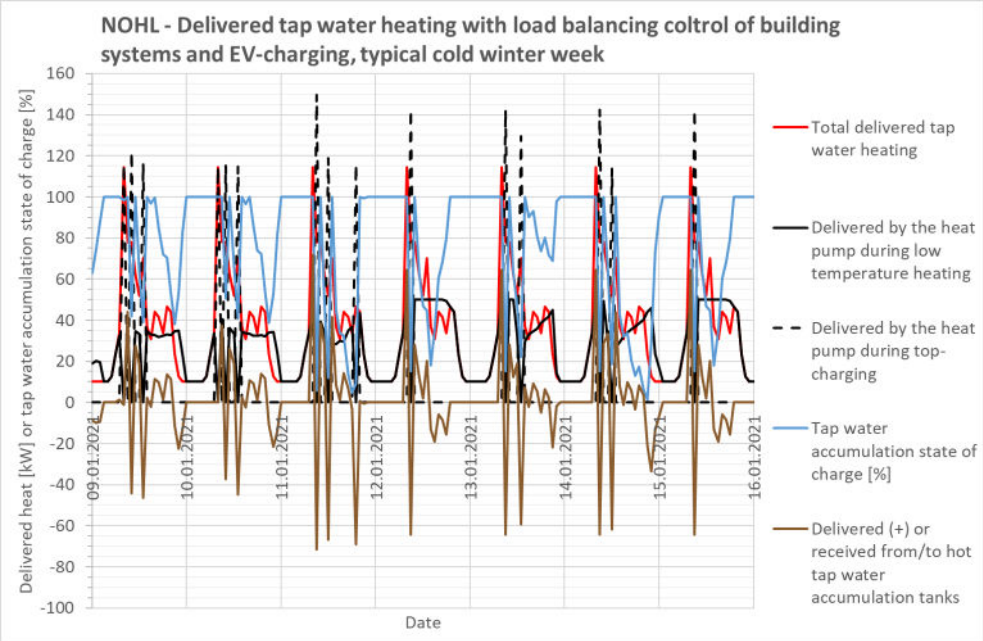


Fig. 8. Lindesnes Helsehus, production, delivery and storage of hot tap water during a cold winter week.

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Table 3. Assumed temperature from the earth heat exchanger

Month	Assumed temperature from the earth heat exchanger [^{0}C]
January	5
February	4
March	5
April	6
May	7
June	8
July	9
August	10
September	9
October	8
November	7
December	6

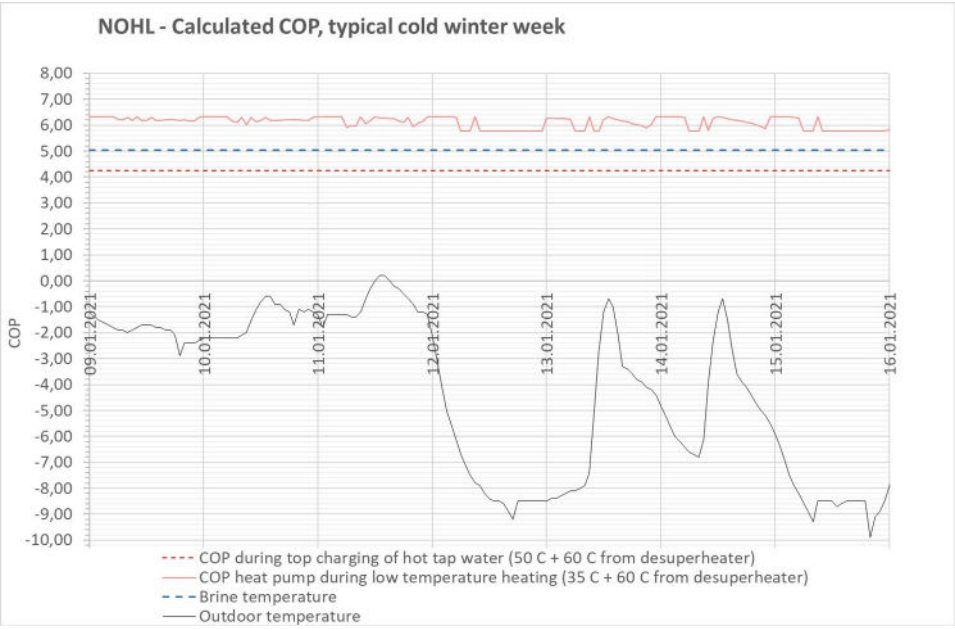


Fig. 9. Lindesnes Helsehus, calculated hourly COP for the heat pump during a typical cold winter week.

4.2.2 The cooling season

Figure 17 shows delivered cooling through a warm sunny week. Heat from the cooling system is accumulated in the thermal storage, and used as source for tap water heating via the heat pump.

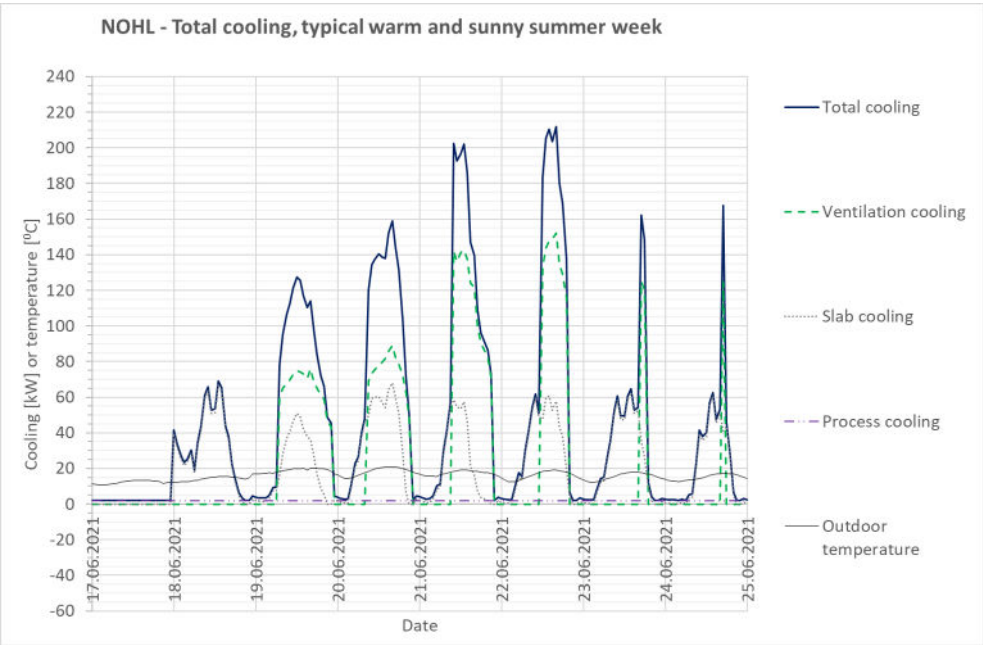


Fig. 10. Lindesnes Helsehus, total cooling delivered by *Inotherm*⁺ through a warm, sunny summer week.

4.2.3 Total performance

The total calculated yearly performance of the system is summarized in Table 4 below.

Table 4. Calculated performance of the *Inotherm*$^{+}$ system.

NOHL *Results Inotherm* $^{+}$	
Space and ventilation heating:	
Total yearly net demand [KWH/year]	345 499
Net demand covered by Inotherm+ [KWH/year]	327 529
Total yearly gross demand (including losses) [KWH/year]	389 460
Total gross heat delivered by Inotherm+ [KWH/year]	371 412
Electricity delivered to the heat pump to cover the gross space- and ventilation heating demand [KWH/year]	56 390
Electricity delivered to the circulation pumps to cover the gross space- and ventilation heating demand [KWH/year]	8 897
Total electricity delivered to the heat pump and circulation pumps to cover the space- and ventilation heating demand [KWH/year]	65 288
SCOP1$_{_SH}$=Gross space and ventilation heat delivered/heat pump power consumption	6,6
SCOP2$_{_SH}$=Gross space and ventilation heat delivered/(heat pump + circulation pumps power consumption)	5,7
SCOP3$_{_SH}$=Net space and ventilation heating demand/(heat pump + circulation pumps power consumption)	5,8
Tap water heating:	
Net demand, tap water heating [KWH/year]	261 663
Total yearly gross tap water heating demand (including losses) delivered by Inotherm+ [KWH/year]	327 707
Electricity delivered to the heat pump to cover the gross tap water heating demand [KWH/year]	65 729
Electricity delivered to the circulation pumps to cover the gross tap water heating demand [KWH/year]	7 850
Total electricity delivered to the heat pump and circulation pumps to cover the tap water heating demand [KWH/year]	73 580
SCOP1$_{_WH}$=Gross tap water heat delivered/heat pump power consumption	5,0
SCOP2$_{_WH}$=Gross tap water heat delivered/(heat pump + circulation pumps power consumption)	4,5
SCOP3$_{_WH}$=Net tap water heating demand/(heat pump + circulation pumps power consumption)	4,0
Total heating:	
Total yearly net demand [KWH/year]	122 120
Net demand covered by Inotherm+ [KWH/year]	589 192
Total gross heat delivered by Inotherm+ [KWH/year]	699 119
Totalt circulation pump power consumption [KWH/year]	16 748
Total electricity delivered to the heat pump and circulation pumps to cover the total heating demand [KWH/year]	138 867
SCOP1$_{_TOT}$=Gross total heat delivered/heat pump power consumption	5,7
SCOP2$_{_TOT}$=Gross total heat delivered/(heat pump + circulation pumps power consumption)	5,0
SCOP3$_{_TOT}$=Total net heating demand/(heat pump + circulation pumps power consumption)	4,2
Energy balance, earth heat exchanger:	
Total heat from energy wells and the cooling system [KWH/year]	565 409
Total free cooling from the earth heat exchanger = heat delivered to energy wells and/or the heat pump [KWH/year]	73 814
Total heat from the PV-T system	491 595
Energy balance for the earth heat exchanger = heat from the cooling- and PV-T system minus heat from the wells in winter [KWH/year]	0

5 Conclusions

Simulation of the proposed design gives a total energy result of 4,021,724 kWh/year (100.6 %) vs the reference building, of which a total solar power production of 783,427 kWh/year.

The resulting SCOP1 for the heat pump in the Inotherm+ system is 6,6 for space- and ventilation heating, and 5,0 for domestic hot water heating.

6 Further work

The project has now entered the detailed design phase, and further work will mainly focus on the following:

- Detailed planning and optimization of all the system components and the system design through integrated energy design (IED).
- Detailed planning and optimization of the load balancing control system.

Optimization will include the use of advanced simulation tools such as SIIEN 7, Modelica, Earth Energy Designer (EED) and spreadsheet tools developed for various purposes.

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