TR A7510- Unrestricted

Report

Energy use in non-residential buildings -possibilities for smart energy solutions

Report 1.1

Author(s)
Ole Stavset
Hanne Kauko

SINTEF Energy Research
Efficient Energy usage
2015-02-05

SINTEF

SINTEF Energi AS
SINTEF Energy Research
Address:

NO-
NORWAY

Telephone:+47 73597200
Telefax:+47

energy.research@sintef.no
www.sintef.no/energi
Enterprise /VAT No:
NO 939 350 675 MVA

KEYWORDS:
Energy use in non-residential buildings
Thermal energy systems

Report

Energy use in non-residential buildings - possibilities for smart energy solutions

Report 1.1

VERSION
1

DATE
2015-02-05

AUTHOR(S)
Ole Stavset
Hanne Kauko

CLIENT(S)
INTERACT

CLIENT'S REF.
228656/E20

PROJECT NO.
502000471

NUMBER OF PAGES/APPENDICES:
39 + Appendices

ABSTRACT

The first part of this report discusses the energy use in non-residential buildings through a literature survey. The questions addressed are the division of energy use according to different purposes, correspondence between measured and calculated energy use and future trends in the energy use. The building categories discussed in more detail are office buildings, commercial buildings, hospitals and educational buildings. The energy use in these building types varies greatly, both considering the specific energy use, and energy use according to the purpose. When comparing measured and calculated energy uses, big deviations have been reported in all the discussed building categories such that the calculated energy is clearly lower than the measured use for new buildings, and vice versa for old buildings. To be able to understand this deviation and to better model the building energy use, better measurement data, as well as more accurate input data are needed.

The second part of the report presents case examples of buildings and building complexes with integrated energy solutions and systems for waste heat utilization. From the case studies it could be concluded that such system solutions generally consist of and energy storage, heat pumps, and a connection to the district heating system to cover the peak load. Utilization of waste heat is seen as a good energy efficiency measure, enabling reductions in both heating and cooling demands, as well as reducing the overall energy costs. Interaction of the energy supply of different buildings for better utilization of waste heat is however so far little practiced.

PREPARED BY
Hanne Kauko

SIGNATURE
Hanne Kauko

CHECKED BY
Michael Bantle

SIGNATURE
Michael Bantle

APPROVED BY
Petter E. Røkke

SIGNATURE

REPORT NO.	**ISBN**	**CLASSIFICATION**	**CLASSIFICATION THIS PAGE**
TR A7510	978-82-594-3640-5	Unrestricted	Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
1	2015-02-05	Final

Table of contents

1 Introduction

This report has been written as a part of the INTERACT project[1] and discusses the energy use in non-residential buildings and building complexes, i.e., by the service industry, as well as the possibilities for exploitation of surplus heat and cool flows in such buildings through case examples.

Buildings account for more than 40% of the global energy consumption, and as much as one third of the global greenhouse gas (GHG) emissions, both in the developed and the developing countries [1]. In Norway, buildings accounted for approximately 40%, or 80TWh, of the total energy use in 2011. This includes the energy used in households (ca 40TWh) and within the service industry (ca 30TWh), as well as the portion of the energy consumption in construction and primary industry that goes to buildings [2]. If energy efficiency in the building sector is not improved, the current energy demand in the buildings sector is expected to rise by 50% by 2050 [3]. Energy efficiency refers to using less energy to provide the same services [4] – for instance heating, cooling and electricity for buildings. This implies reducing the heating and cooling demand, for instance through a better insulated building envelope, as well as using alternative methods for heating, e.g. using heat pumps or renewable energy sources instead of direct electricity.

The energy demand is high in many industrial and non-residential buildings, and at the same time these buildings often have processes or equipment with high production of excess heat. This may be for instance computer facilities at universities, refrigeration systems at supermarkets or restaurants, or technical equipment at a hospital. Utilization of this excess heat would be a good way to reduce the energy use. However technical barriers for utilizing the excess heat are various: the heat might be available at a too low temperature, the availability of excess heat and heat demand may not coincide, or the utilization of the excess heat is not otherwise feasible. Luckily, there are also cases when excess heat can be relatively easily utilized, as will be shown in this report.

The first part of this report focuses on energy use in non-residential buildings and building complexes. Questions to be addressed in this part are energy use according to the purpose as well as the differences between calculated and measured energy use for different building categories. Understanding the variation in energy use according to the purpose for different building categories is important for planning the energy supply system for different buildings, as well as for planning the utilization of possible surplus heat and cool flows. The results on measured energy use in different building categories could further be used for model calibration. In the second part, examples of integrated energy solutions and ways to utilize surplus heat in some existing buildings and building complexes are presented. Apart from a detailed description of the system solution, measurements and experiences are presented, when such information was available. Gathering data for actual energy use in buildings is difficult and time-consuming, and setting up energy meters is resource intensive; however the work on actual energy use will be continued in the future.

---

[1] The competence-building research project for the industry 'Efficient interaction between energy demand, surplus heat/cool and thermal storage in building complexes – INTERACT' is a 4-year project (2014-18) with main funding from industrial partners and the Research Council of Norway, and coordinated by SINTEF Energy Research.

2 Energy use in non-residential buildings

Figure 1 presents the specific energy use – i.e., energy use per square meter – for different non-residential buildings in Norway in 2011, according to the building year. What is interesting to notice in this figure is that the specific energy use is not necessary lower for newer buildings. Even though the building regulations have become stricter regarding e.g. the tightness of the building envelope, the amount of technical equipment and the operation time have increased in many building types, and the requirements for indoor air quality have become higher. The reasons for this discrepancy will be discussed further in the following sections, in context with a more detailed inspection of the energy use of certain individual building categories.

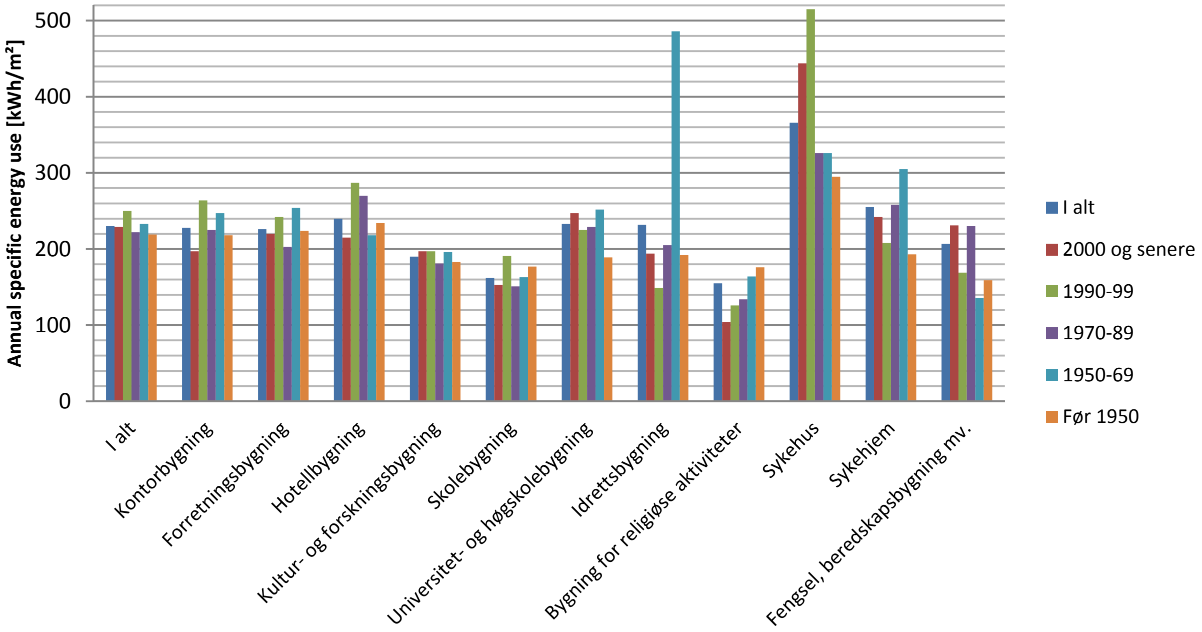


Figure 1 Annual specific energy use according to the building category and building year in Norway in 2011 (SSB 2013).

The overall average annual specific energy use was 230 kWh/m²; however this varies a lot among the different building categories. The category with clearly highest specific energy use is hospitals, with on average 366 kWh/m² in 2011, followed by nursing homes, sports buildings and hotels. In sports buildings, there is a significant peak in facilities built in the period 1950-69. This is probably related to the high number of swimming facilities built in this period [5]. For comparison, the average specific energy use for households was 185 kWh/m² in 2012 [6].

The specific energy use in a certain building type depends primarily on the operation time, location, amount of technical equipment (appliances), and the focus on energy efficiency measures. From Figure 2 it can be seen that for many building types there is a clear correlation between the specific energy use and the operation time per day. Hospitals and nursing homes have the highest specific energy use, owing to the high operation time, high demand for ventilation air and high amount of technical equipment. Schools (including primary and high schools and kindergartens), on the other hand, have the lowest energy demand due to the relatively low operation time and low amount of technical equipment. Buildings for religious activities have usually low operation time, but often a high ceiling, which increases the heating costs.

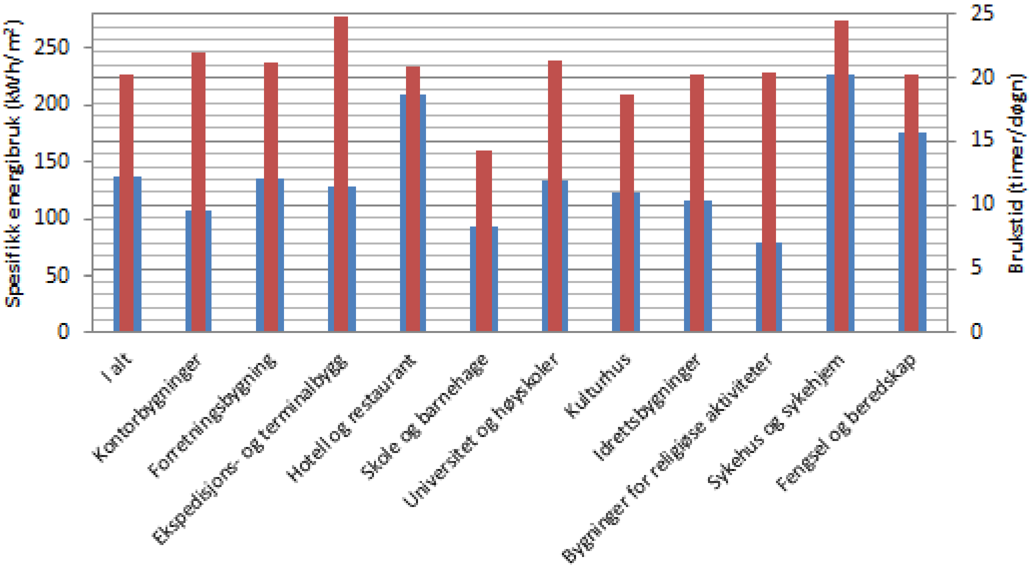


Figure 2 Specific energy use and operation time in different building types [7].

The total energy use of a certain building category depends not only on the specific energy use but obviously also on the total number and area of the buildings in this category. Figure 3 presents the number of buildings in each category, while Figure 4 presents the total heated areal for each category. Excluded from the figures are residential buildings, which dominate in the number of buildings (1 459 727 in 2010 [8]), as well as in the total built areal (255,6 mill m² in 2010 in gross areal [9]). The data from Figure 3 and Figure 4 combined with the specific energy use could be used for energy planning of building complexes. This data provides also a good starting point for estimating the frequency of a specific building category in a building complex. For example, the results show that apart from residential buildings, commercial and office buildings as well as industrial buildings dominate in the total built heated areal. In the number of buildings, industrial and storage buildings lie highest, however some of these buildings maybe unheated. Buildings for education, culture and research lie on the second place. The relatively low number of office and commercial buildings reflect the high areal of these buildings: office buildings have an average heated areal of 3473 m² [10], shopping centres have an average areal of 13 036 m² and grocery stores 2 601 m² [11] (Entro's database).

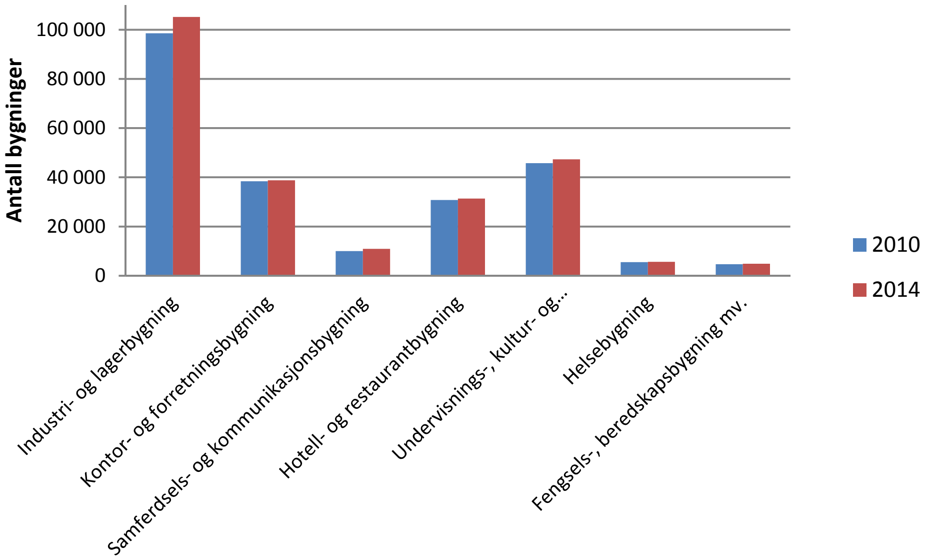


Figure 3 The total number of buildings for different building types in Norway in 2010 and 2014 [8].

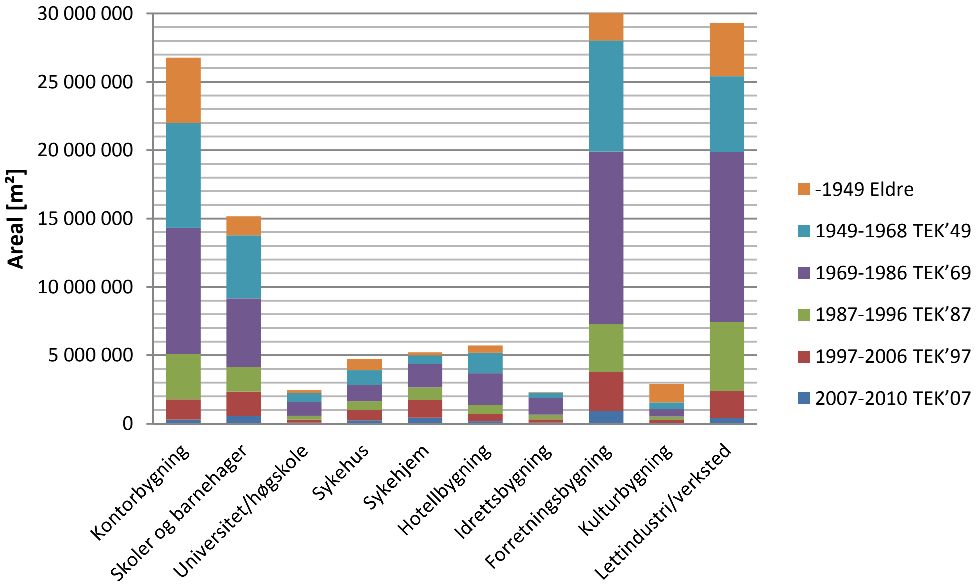


Figure 4 Heated building areal for different building types according to building year in 2010 [9].

In this chapter, the energy use according to the purpose, future trends in energy use and correspondence between calculated and measured energy use will be discussed in more detail for some building categories: office buildings, commercial buildings, hospitals and education buildings. The building categories presented differ greatly in both the specific energy use, usage patterns as well as the division of the energy use for different purposes.

2.1 Office buildings

In office buildings, energy is used primarily for room heating (through ventilation and radiators), technical equipment, lighting, and cooling. Figure 5 presents the calculated energy use according to the different building regulations, divided according to the purpose. According to the calculations the specific energy for room heating (including heating through air-conditioning (AC)) has reduced significantly, from 97 kWh/m^2 based on the building regulations of 1987 to 40 kWh/m^2 based on TEK10 [10]. At the same time the share of energy used to other purposes – technical equipment, lighting, and in particular cooling– has increased.

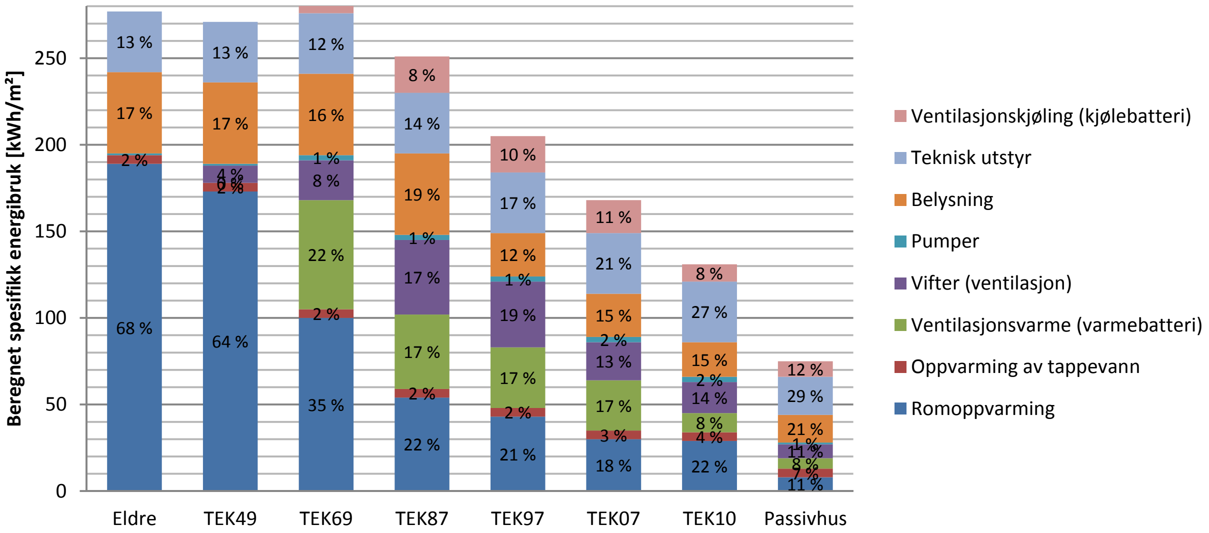


Figure 5 Calculated specific energy use in Norwegian office buildings according to the purpose, based on different building regulations [10].

For Norwegian office buildings, measured energy use divided according to the purpose is not available [10]. Similar data was however available for Swedish office buildings for 1990 and 2005 [12], see Figure 6. In Swedish office buildings, heating is primarily supplied by district heating, but in other aspects it could be assumed that Swedish office buildings represent the Norwegian buildings well. For 1990, the total specific energy use was 217kWh/m^2, out of which 94kWh/m^2 went for other purposes than heating. For 2005, the total specific energy use was 193kWh/m^2, out of which 93kWh/m^2 was for other purposes than heating. The share of heating and lighting from the total energy use decreased from 1990 to 2005, while the share of cooling and fans (i.e., ventilation) and other electric devices (including computers and servers) increased from 9% (20 kWh/m^2) to 14% (28 kWh/m^2) and from 17% (38 kWh/m^2) to 19% (36 kWh/m^2), respectively.

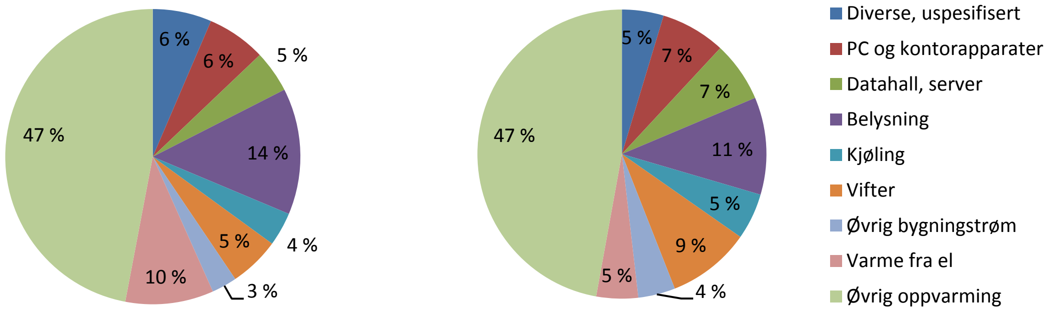


Figure 6 Purpose-divided energy use for Swedish office buildings for 1990 (left) and 2005 (right) [12].

Comparing the values from Figure 6 to the respective values for calculated energy use in Figure 5 (TEK87 and TEK97 or TEK07), one can find some similar trends. The share of heating and lighting of the total energy use is lower for newer buildings, while the share of cooling, fans and technical equipment is higher, both for calculated and measured energy use. On the other hand, according to the calculations the actual share of heating is lower, and the share of lighting and fans is clearly higher for both cases (older and newer) when comparing to the measured use. The total calculated specific energy use is in this case, surprisingly, higher (251 kWh/m^2 for TEK87, 205 kWh/m2 for TEK97) than the actual energy use (217 kWh/m² for 1990, 193 kWh/m² for 2005). This might be related to different rate of renewal of the Swedish building regulations – if one uses TEK07 as a reference, the value is clearly lower for the calculated energy use (168kWh/m²).

2.1.1 Calculated vs measured energy use

In Figure 7, the total measured energy use of Norwegian office buildings is compared with the calculated use for different building years. According to this figure, the actual energy use in office buildings has not decreased in until the very recent years. The reasons for this are various. For Norwegian office buildings the calculations for heating, DHW and lighting are often in accordance with the actual use; however the energy use for ventilation, fans, pumps and cooling is generally higher than assumed in calculations [10]. Higher energy use for ventilation and cooling might be due to different occupant pattern and operation than expected in the calculations, together with high requirements for indoor air. The actual operation time might be higher than the one assumed in the calculations, increasing the energy required for heating, ventilation and lighting. It might further be that the construction and operation of the building has not been conducted in the most optimal way; the actual climatic conditions may deviate from the normative ones; and the measured energy use (based on monitoring systems and energy bills) may be erroneous. Finally, it might be that the simulation tools used to calculate energy use do not describe the problem properly or that the input data are not proper.

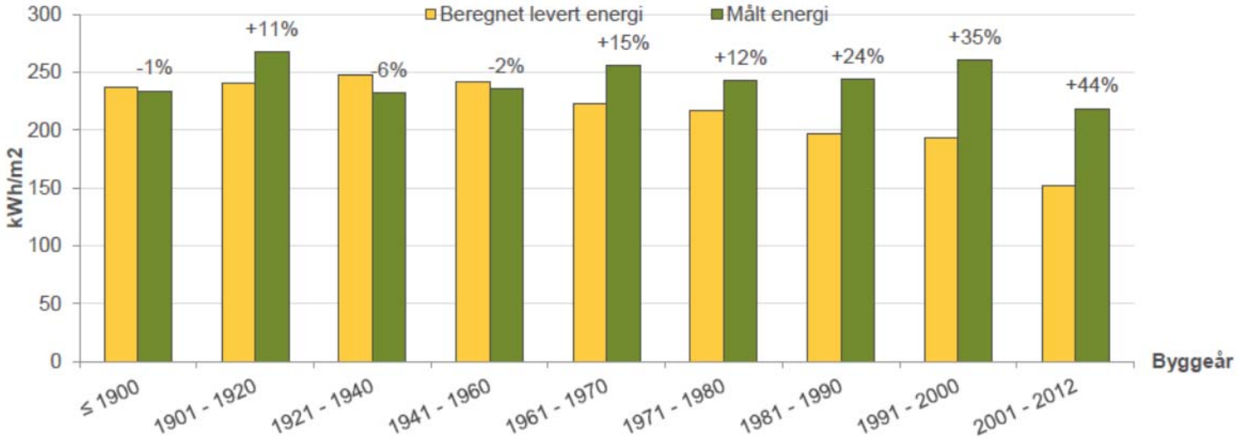


Figure 7 Calculated delivered energy (yellow) vs measured energy (green) according to the building year for Norwegian office buildings [10].

2.1.2 Future trends

The energy demand for heating is expected to reduce further due to tightening building regulations [10]. Similarly the energy for lighting is expected to reduce due to upgrading to more energy efficient lights, such as LED technology. The energy used for ventilation, fans and pumps is expected to gradually reduce due to better, more efficient technology. It is further expected that more energy efficient technical equipment will be used, however simultaneously the amount of installed equipment is expected to increase, causing little change in the total energy use. Finally, regarding cooling, the development of the energy use is uncertain: the requirements for solar shielding are becoming stricter, however tighter building envelopes will result in a higher amount of excess heat in the buildings.

2.2 Commercial buildings

Commercial buildings include for instance grocery stores, clothing stores, shopping centres and gas stations [11]. From these buildings, grocery stores have the highest specific energy use with ca 460 kWh/m²·year (based on NVA's statistics), while shopping centres have a specific energy use of ca 300 kWh/m²·year. The total energy use in commercial buildings in Norway is almost 11 TWh/year, which corresponds to 30% of the energy use in non-residential buildings.

Figure 8 and Figure 9 present the energy use according to the purpose for shopping centres and grocery stores, respectively. From Figure 8 it can be seen that in shopping centres, the biggest post is electricity to the tenants, including lights and electric equipment. The energy demand for lighting is high due to display of products. The second largest posts are heating and ventilation, and cooling is also relatively high. The total energy use was 316 kWh/m²·year for the shopping centres presented here.

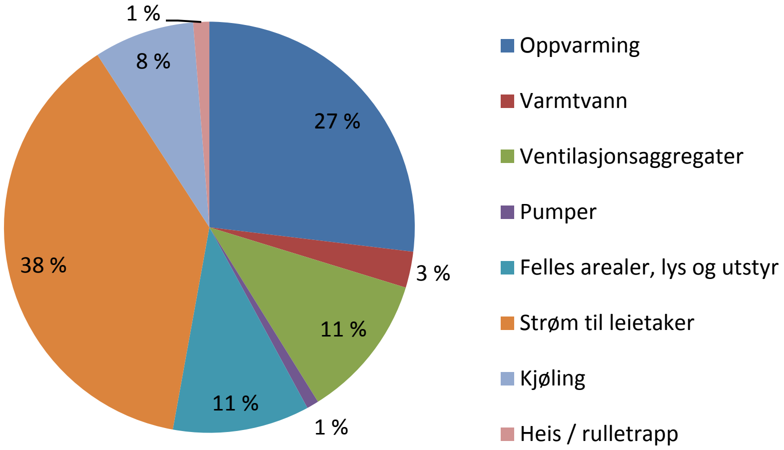


Figure 8 Annual specific energy use according to the purpose for shopping centres (representative values for 10 shopping centres from Entro's database) [11]. The total energy use was 316 kWh/m²·year.

In grocery stores (Figure 9), decidedly most energy is used for the refrigeration systems (central and plug-in), which account for 48% of the total energy use. Thereafter the biggest energy sinks are lighting, pumps and technical equipment, and ventilation. The energy used for heating domestic hot water (DHW) is generally low in commercial buildings. The total energy use was 599 kWh/m²·year for the grocery stores presented here.

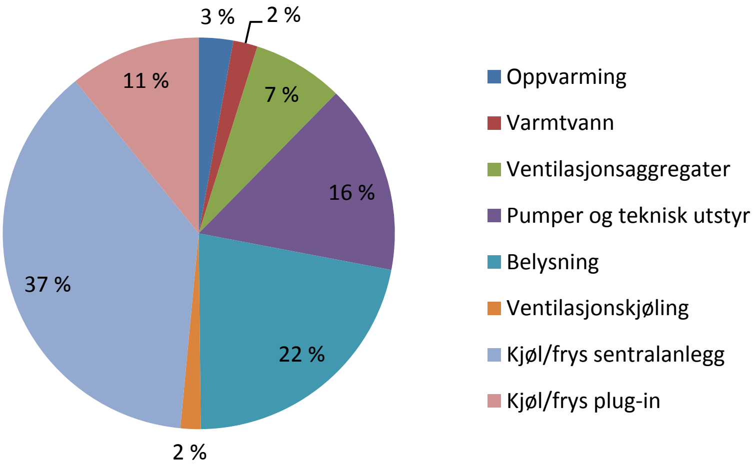


Figure 9 Annual specific energy use according to the purpose for grocery stores (representative values for 5 stores based on a study by ICA Norge/grid owner/Multiconsult) [11]. The total energy use was 599 kWh/m²·year.

2.2.1 Calculated vs measured energy use

Energy calculations are based on normalized input data from building standards for DHW use, lighting, operation times, temperature set-points, and so forth. Similarly to office buildings, the calculated energy use for commercial buildings is generally lower than the measured use [11]. The deviation is high in particular for grocery stores, most probably because the standardized values for energy use of the refrigeration systems is underestimated. Another reason for the big difference between calculated and measured energy use might be that the used calculation methods (simulation tool) are not suitable for modelling commercial buildings and grocery stories.

2.2.2 Future trends in energy use

Factors leading to an increasing trend to the energy use in commercial buildings are for instance prolonged opening hours and higher need for refrigeration due to increased demand for pre-prepared food; while decreasing factors are more strict building regulations and building energy certificates. Switching to LED lights will serve as a big potential for reduction in lighting-related energy use in commercial buildings, although this will reduce internal heat gains somewhat. Further important energy efficiency measures are exploitation of the waste heat from the refrigeration systems, and optimising the operation of the heating and ventilation systems.

2.3 Hospital buildings

Hospitals are among the buildings with the highest specific energy use. According to the Norwegian building regulations (TEK10), the maximum allowed annual specific energy use is 300 kWh/m²·year for hospital, and 335 kWh/m²·year for areas where heat recovery of ventilation air involves a risk of contamination of supply air. The actual energy use for Norwegian regional and university hospitals is around 394 kWh/m² [13], while smaller local hospitals with fewer functions use approximately 18% less [14]. Hospitals with laboratory activities have generally high specific energy use. St Olav's Phase 1, developed in the years 1999-2005, has an annual specific energy use of 402 kWh/m²; Rikshospitalet was designed for an energy intensity of 441 kWh/m² but performs better after more energy measures were implemented. Phase 2 of St Olav's is aiming at 323 kWh/m² [13]. The Knowledge Centre St Olav's, which will be discussed in more detail in section 3.1.2, is aiming at a passive house level and a net energy demand of 127 kWh/m². This centre has however only few laboratory activities, and no other common hospital functions.

Figure 10 presents the energy use according to the purpose for 2010 for a big Norwegian regional hospital built in 2008, with a total annual specific energy use of 417 kWh/m². Note that the data is not temperature corrected, and 2010 was 8% colder than a normal year. The biggest individual energy post is heating of ventilation air, with 27% (111 kWh/m²) of the total energy use. This is more energy demanding in hospitals than in many other buildings as use of regenerative (e.g. rotating) heat exchangers with high efficiency is limited in due to mixing of exhaust and supply air, and hence possible contamination of the supply air. Furthermore, high demand for ventilation air is characteristic of hospitals, thus heat is primarily distributed by ventilation air and secondarily by radiators, which corresponds to only 12% (52 kWh/m²) of the total energy demand. Apart from ventilation and room heating, high temperature heat is required for various hospital functions, and low temperature heat for snow melting. Cooling demand is also high for this particular hospital, corresponding to 16% (65 kWh/m²) of the total energy demand. An inspection of the monthly variation of the cooling demand showed that the demand is mostly due to processes in the hospital rather than comfort cooling [13]. Typical value for ventilating cooling in Norwegian hospitals is 15 kWh/m². Approximately one third of the energy demand goes to electrical equipment, primarily lighting and technical (hospital specific) equipment.

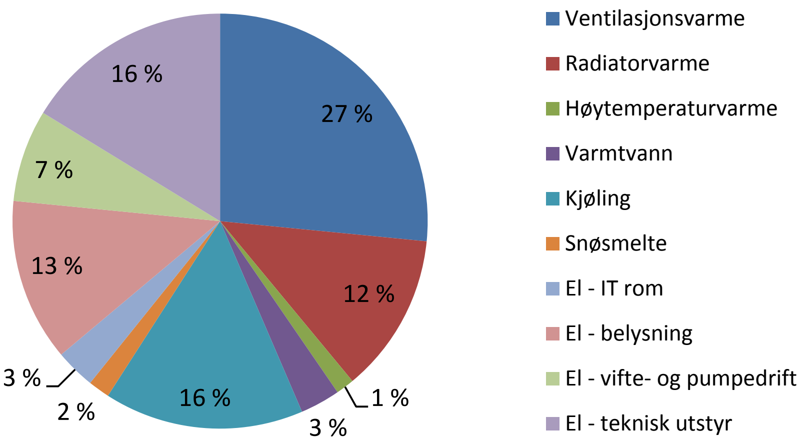


Figure 10 Energy use according to the purpose for year 2010 for a big Norwegian regional hospital built in 2008 with 500 sleeping accommodations, an area of 113 000 m² and a total specific energy use of 417 kWh/m² [13].

2.3.1 Calculated vs measured energy use

Studies were the calculated and measured energy use had been compared was not found, however the assumption is that the real energy use overestimates the calculated energy use, similarly with other building types. For instance hospital equipment is a major contributor to whole-building energy use, and their real energy use is difficult to estimate realistically due to e.g. varying operation patterns [15].

2.3.2 Future trends in energy use

Reducing energy use in hospitals is not as straightforward as in other building types, as many energy efficiency measures may reduce the patient security. There are however several efforts towards low-energy hospitals, such as the knowledge building project for low-energy hospitals[2], aiming for halving the energy demand of new hospitals. Possible energy efficiency measures are for instance optimizing the building shape and reducing glass areal in atriums, integration of the different energy supply systems, increased ventilation heat recovery and increased utilization of waste heat form cooling units [13], [14].

2.4 Educational buildings

Educational buildings, covering kindergartens, schools and university buildings (including universities and university colleges), are moderate energy users. The average specific energy use (purchased energy) is estimated to be 200 kWh/m² for Norwegian kindergartens, 170 kWh/m² for schools and 260 kWh/m² for university buildings [16]. Energy use according to the purpose for these three building types is presented in Figure 1. The values presented are chosen as representative values from detailed analysis of several individual buildings

---

[2] http://www.lavenergisykehus.no/

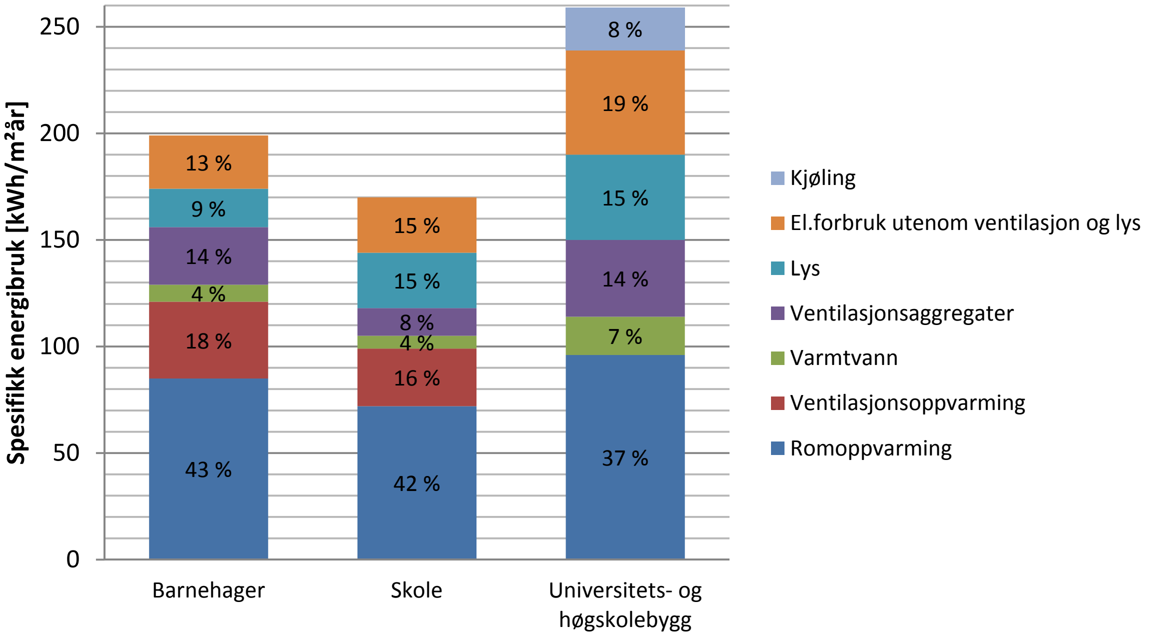


Figure 11 Energy use according to the purpose for educational buildings: kindergartens, schools and universities [16].

The high specific energy use of kindergartens with respect to schools is related to higher indoor temperatures, smaller buildings and longer operation times. The indoor temperature is often kept as high as around 24°C so that small children would not feel cold (Multiconsult AS, Analyse & Strategi AS et al. 2014). Consequently, most energy is used for heating, which accounts for 60% of the total energy demand. Heating is usually supplied with electric radiators. Relatively high amount of energy (13%) is also consumed for household appliances (refrigerators, dishwashers etc). The operation times are long as many kindergartens are open also in the summer holidays. On average, kindergartens are in use 10 hours per day, 5 days per week.

The relatively low specific energy use of schools is primarily due to the low operation hours: most schools are in operation 7-8 hours 5 days per week, and many are kept close 12 weeks during a year owing to school holidays [16]. The air handling unit is off during these periods, leading to a surprisingly low (8%) share of energy used for ventilation. The biggest energy post is heating, with in total 58% of the total energy demand. In most schools heating is supplied by electricity (electric radiators, 63% of the schools in Entro's database), but district heating is also widely applied (28%). Electric boilers in combination with oil or biomass boilers are also in use (9%). Similarly to kindergartens, the energy used for lighting is fairly modest, as often energy efficient lights are used.

Universities differ from the first two with longer operation times, and the need for high number of computers as well as computer rooms and server halls with high energy demand. Energy use for electric appliances presents the second largest (19%) energy post after heating, which accounts for only 37% of the total energy demand. Universities are further the only educational buildings with a demand for cooling, owing to the high internal heat load. The energy use for DHW supply is also clearly higher than in schools and kindergartens, which can be explained with the longer operation hours, as well as the presence of a number of cantinas and cafés in university buildings.

2.4.1 Calculated vs measured energy use

For both kindergartens, schools and universities, the calculated energy use is lower than the actual use for older buildings, and higher than the actual use for newer buildings [16] – similarly with the other building types presented in this report. There are several reasons for this. For instance for ventilation rate, normative minimum values are used in calculations for all building years. The actual ventilation rate is however probably lower in older buildings, leading to lower energy use but also lower indoor air quality. To thoroughly understand the reasons for the deviation between calculated and measured use, a detailed comparison between all the input data and measured data from a representative building is needed.

2.4.2 Future trends

The total heated areal of educational buildings, especially schools and kindergartens, is directly correlated with the population; and as the population is increasing, the total areal and hence also the total energy use will increase. At the same time building size is increasing and the specific energy use is reducing owing to the stricter building regulations. In kindergartens in particular, the specific energy demand is expected to decrease due to better insulated buildings and hence reduced heating demand. Indeed, in some newer kindergartens the heating demand was a quarter of the value presented in Figure 11 [16].

Other trends inducing higher energy demand for schools and kindergartens are prolonged operation hours due to renting out the premises for evening use, and for schools in particular the continuously increasing amount of IT equipment and other electrical appliances. Many of these appliances are plugged in, and hence cause unnecessary electricity use also in the night-time. Further trends for decreasing energy use in educational buildings are, similarly with other building categories, increased environmental focus and as a result ambitious goals for reduced energy use through building energy certificates, as well as increased focus on good building management.

2.5 Discussion and Conclusions

The energy use in different building categories varies a lot, both with respect to the specific energy use, and the division of the energy use for different purposes. The biggest energy consumers are hospital buildings, with a specific energy use of approximately 400 kWh/m²·year. In hospitals, most energy is used for heating, provided primarily through ventilation, and thereafter for lights and technical equipment. Followed by hospitals are commercial buildings: shopping centres (300 kWh/m²·year) and grocery stores (460 kWh/m²·year). For shopping centres, the main energy posts are heating, ventilation and lights for the display of merchandise; for grocery stores, the refrigeration system dominates the energy consumption. For office buildings (230 kWh/m²·year), the energy use is dominated by heating, ventilation, electric devices and lighting. The lowest energy users are schools (170 kWh/m²·year) and kindergartens (200 kWh/m²·year) owing to their low operation times, with energy use being dominated by heating. The energy use of university buildings (260 kWh/m²·year) reminds that of office buildings, with high share of electricity used for electrical appliances. As the energy demand is different, should also the energy supply system be different – adapted to the needs of a certain building type.

There are big deviations between the measured and calculated energy use for all the building types discussed, such that the calculated energy use is higher than the measured one for old buildings, and vice versa for new buildings. In the reviewed studies, the calculation method has not been discussed. In general, the building energy demand calculation is performed to prove that the buildings are fulfilling the Norwegian building regulations (TEK10), not for the purpose of a detail performance analysis. This might be one of the reasons for mismatch between the calculated and real energy use. Furthermore, newer buildings have newer and more complicated equipment that is often not properly modelled by the calculation tools – this applies to for instance the technical equipment in hospitals and refrigeration systems in supermarkets, as discussed earlier. Heating demand is usually well predicted by the calculations; however the amount of energy required for cooling and ventilation is generally underestimated for newer, and overestimated for older buildings. Moreover, the usage patterns and operation times often deviate from the assumed ones.

It is also difficult to get reliable measurement data, in particular for energy use according to the purpose. The measured energy uses are usually based on questionnaires sent to the building owners and managers [17], and the responses are usually based on energy bills, which do obviously not give information on where the energy was used, and might otherwise be erroneous. Few buildings are equipped with energy meters [11], and owners of such buildings are often more engaged in energy efficiency than average building owners – for instance buildings that have received support for energy efficiency measures from Enova are required to record their energy usage [18]. The data from such sources is hence somewhat biased. The meters might further be installed only to some parts of the building, depending on the ownership of the building areal [5, 11]. Moreover, the collected data depends on the sampling, and might contain different statistical errors related to for instance the size and geographical location of buildings in the dataset, and definition of a certain building type [11, 17].

The data presented here may nevertheless be useful from several aspects. Firstly, as mentioned above, understanding how energy is used by different building types is important for successful design of an energy supply system, as well as for increased utilisation of excess heat in buildings and building complexes. It is also important to know where the building energy calculations fail to predict the actual energy use. The reported deviation between measured and calculated energy use calls for more precise building models, as well as better data for the measured energy use for different purposes. Data for measured energy use could be used for calibrating the building simulation models. By relating the measured energy use and building frequency data, it is possible to predict the energy demand of building complexes.

3 Case studies

3.1 St Olav's Hospital

St Olav's hospital has been going through an extensive development where some of old the buildings have been renovated, and many new buildings have been built [19]. The construction work was finished in 2014. The hospital, with a total area of 226 000 m² (heated areal 216 000 m²), has been planned as a hospital of the future from both patient, employee and environmental point of view. Environment has been considered in logistics, in the construction – 98% of an old hospital building, "høyblokka", was either re-used or recycled – and in the energy supply. One of the new buildings, Kunnskapssenteret, discussed in more detail below, is built in passive house standard. Furthermore, excess heat from the refrigeration systems at Akutten– & Hjerte-Lunge-senteret (AHL) is utilized in pre-heating DHW for three different hospital buildings. This system is also discussed in more detail below.

The hospital is nevertheless an extremely energy intensive building complex. The total energy use in 2012 was 137GWh (634 kWh/m²), out of which 40GWh (183 kWh/m²) was electricity, 27GWh (125 kWh/m²) district cooling, and 70GWh (326 kWh/m²) district heating [14]. District heating is provided by Statkraft Varme AS, who utilizes mainly combustion of municipal waste in the heat production. The hospital has a special contract for the district heating, with a very low price (0.31 NOK/kWh + VAT in 2013 (Aasen 2013)). District cooling is provided by Øya cooling centre (own by Statkraft Varme AS), which utilizes the water from Nidelva river for free cooling in the wintertime, and for cooling down the condensers of the cooling machine in the summertime. Apart from the compression cooling machine, the hospital has an absorption cooling machine with a capacity of 10 MW run by Statkraft Varme AS, utilizing excess heat from district heating in the summertime [20]. The hospital has its own local network for distribution of heat and cool.

3.1.1 Akutten– & Hjerte-Lunge-senteret

AHL centre is one of the one of the largest and most energy consuming buildings at St Olav's, with an area of ca 40 100 m² and a specific energy consumption of 435 kWh/m²·year, out of which 57 kWh/m² is district cooling, 176 kWh/m² district heating and 203 kWh/m² electricity. The building contains the sterilization centre, delivering sterilized equipment to the entire hospital; and the supply kitchen, an industrial kitchen providing food supplies for the entire hospital. Sterilization is performed with for instance steam, heat and washing machines, and is hence a highly energy demanding process. The supply kitchen has large refrigeration and freezing systems for food storage. Both of these have hence a great potential for utilization of surplus heat.

Figure 12 presents a sketch of the sub-station for heat, DHW and cooling at the AHL centre, together with the refrigeration systems. The condensers generate heat at 35-40°C, and this heat is utilized to pre-heat DHW [14]. The remaining temperature lift is performed with district heating, as is illustrated in the figure. On average 74% of the waste heat is utilized, corresponding to 117 MWh per year, which is 4.3% of the district heating demand. Between 8 and 18 in weekdays the utilization rate is 98%, and on weekends it is reduced to 56%. The heat that is not utilized is dumped to the district cooling network of the hospital – if all the excess heat would be discarded, this would correspond to 26% of the district cooling demand. The use of excess heat from refrigerators for pre-heating DHW is a smart system solution also in the sense that the heat production is highest in the daytime, when also the DHW demand is at its highest.

Later the condenser circuit presented in Figure 12 was extended such that excess heat from the steam production at the sterilization centre was also utilized. No measurement data were available, but it has been estimated that this addition would result into 22% increase in the amount of energy in the circuit [14].

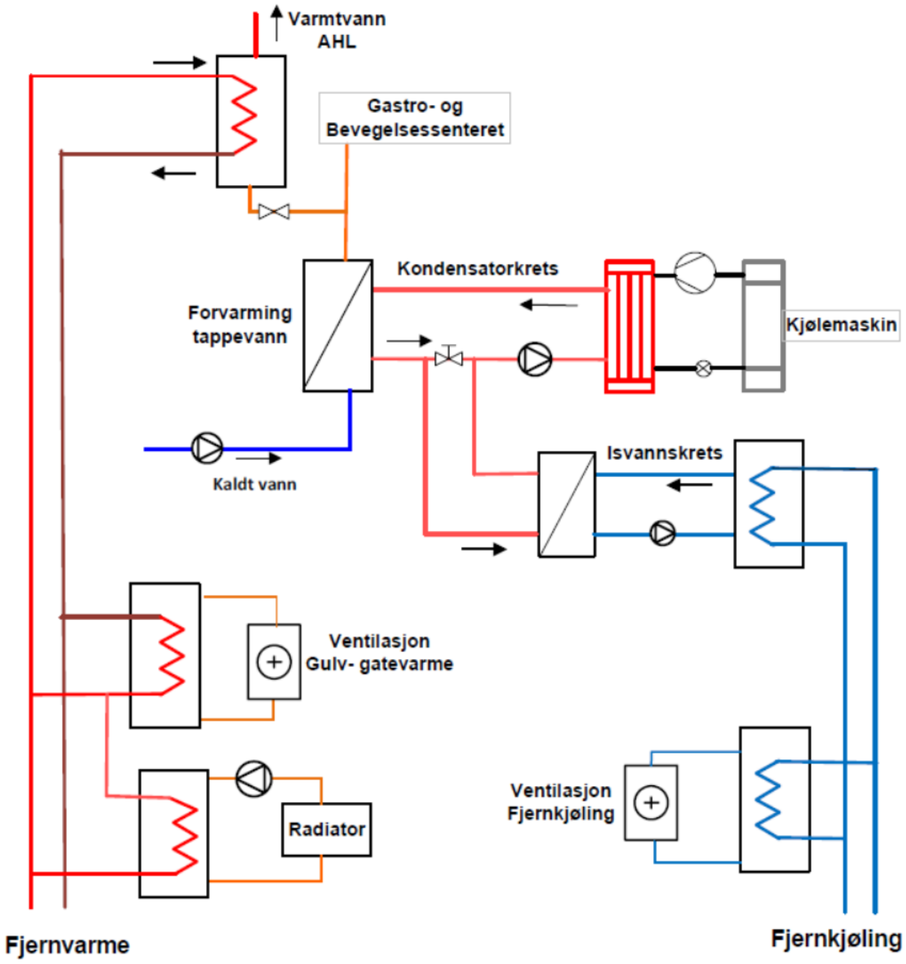


Figure 12 Sub-station for the AHL centre, including DHW and cooling [14].

If the utilization of waste heat was to be increased, this would have to happen in the night time and in the weekends, when the utilization rate is low [14]. This would require a larger hot water storage, in order to smooth out the utilization. Alternatively, several buildings, preferably with high heat demand in the night time or in the weekend, could be coupled to the system. Furthermore, the waste heat could be utilized to heat the supply air for ventilation.

3.1.2 Kunnskapssenteret

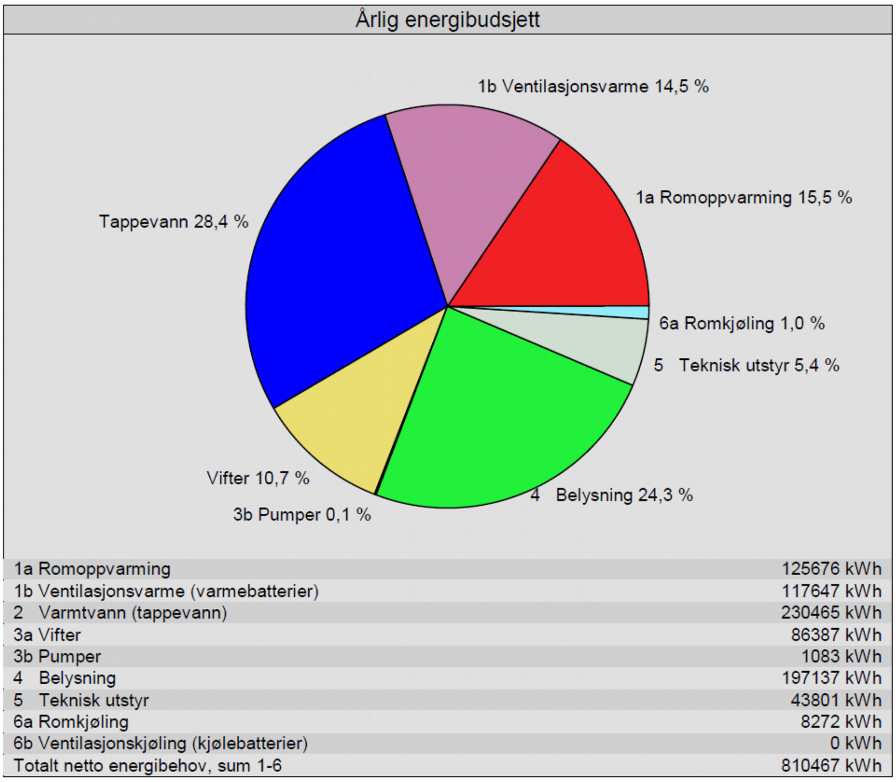
Kunnskapssenteret is the first Norwegian hospital built at a passive house standard. According to calculations, the annual specific energy demand for the centre should lie at 128 kWh/m² [21]. Kunnskapssenteret is however not a pure hospital building, but the total area of 17 500 m² is divided between 6 900 m² of hospital area and 10 300 m² of university area [22], and consists of for instance wards, laboratories, offices, auditoria, as well as a library [21]. The low energy use was achieved through passive measures, such as extra insulation, high building tightness and heat recovery with high-efficiency rotating heat exchangers (temperature efficiency 85%) where it was possible. Other measures are differentiated low-energy lighting, exterior shading and demand control for lights and airflow rate. The heat and cooling demand is covered by the district heating and cooling, and the possibility for exploiting waste heat from the AHL centre has also been considered [22].

3.2 Scandic Hotel Lerkendal

Scandic Hotel Lerkendal in Trondheim has been running since august 2014, and was built with a strong focus on environment and energy efficiency. The hotel has a total area of 10 000 m², with 400 rooms and 21 floors, and is ranked in Energy class A++, which sets a requirement for maximum delivered energy of 50 kWh/m²·year [23]. The measured delivered energy based on the first five months of operation was 69 kWh/m²·year [24]. Attached to the hotel is a 25 000 m² building with offices and a conference centre, built according to Energy class B.

To achieve the low energy use at the hotel, a range of energy efficiency measures has been applied, such as: tight building envelope, with an air tightness of n_{50} = 0.3 h^{-1} (air changes per hour); windows with low U-value (0.7 kWh/m²), and minimum allowed window areal; decentralized ventilation plants (2 at each floor) to optimize the conditions for a high specific fan power (SFP) factor (having many small units enables small duct dimensions and hence more efficient fan operation), and exhaust shafts for low operation costs for exhaust fans; and finally solar shielding and LED lights for minimum heat gain and low energy use. There is also no floor heating installed to the bathrooms. The heating demand is covered with renewable energy sources: air-to-water heat pump, solar thermal, waste heat from the refrigeration system of the hotel, and district heating. The heat supply system is discussed in more detail below.

The annual energy use, simulated with SIMIEN [25], is presented in Figure 13. According to the simulations, heating accounts for 30% of the total energy use, out of which 14.5% is covered by ventilation and 15.5% by low temperature radiators. Almost equal amount of energy is required for DHW preparation: 28% of the total demand. Lighting accounts for 24%, and fans 11% of the annual energy use. The energy for cooling is minimized – no air conditioning has been installed to the building. To ensure low enough room temperatures in warm periods, night cooling is utilized; that is, the warm indoor air is exchanged with fresh outdoor air to cool down the thermal mass of the building in the night time, when outdoor temperatures are low.



1a Romoppvarming	125676 kWh
1b Ventilasjonsvarme (varmebatterier)	117647 kWh
2 Varmtvann (tappevann)	230465 kWh
3a Vifter	86387 kWh
3b Pumper	1083 kWh
4 Belysning	197137 kWh
5 Teknisk utstyr	43801 kWh
6a Romkjøling	8272 kWh
6b Ventilasjonskjøling (kjølebatterier)	0 kWh
Totalt netto energibehov, sum 1-6	810467 kWh

Figure 13 Simulated annual energy use for Scandic Hotel Lerkendal.

3.2.1 Heat supply system

The space heating demand is covered by the air-to-water heat pump, while DHW is supplied by the solar thermal system, waste heat from the refrigerators, and district heating. The solar thermal system is dimensioned to cover ca 50% of the annual DHW demand, and waste heat from the refrigeration system should cover ca 10% (Emmerhoff 2014). The remaining is covered by district heating, which serves also as a back-up, and the system is designed such that district heating can cover 100% of the DHW demand, if needed.

The solar thermal array, shown in Figure 14, consists of 140 modules divided into groups of 10, and has a total area of 350 m² [23]. The array is placed on the roof of the conference centre, facing south, with a tilt angle of 55°. The modules are flat plate solar collectors delivered by SGP Varmeteknikk AS.

Figure 14 Solar thermal array at Scandic Hotel Lerkendal.

Schematic diagram of the entire heat supply system is presented in Figure 15. In the solar collectors, propylene glycol is circulating, delivering heat to three solar stations coupled in cascade. When the temperature from the solar collectors is high enough, the heat is delivered further to four well insulated hot water tanks 5000 l each, storing water at a temperature of ca 55°C. A large hot water reservoir is crucial as the peak DHW demand occurs in the morning, when solar heat is usually not available. From the storage tanks, the heat is further delivered to a tapping centre via plate heat exchangers. With such a system, storage of large amounts of DHW at unfavourable temperatures (subject to Legionella risk) is avoided. The tapping centre extracts hot water from the top part of the storage tanks, and delivers cold water to the bottom part, ensuring a high efficiency. The DHW system is further serially connected to a heat exchanger coupled to the district heating supply for a further temperature lift, when necessary. The heat supply system was designed by Hent AS.

A disadvantage with the solar thermal system is that the peak production period is during the summer, when the hotel also has least visitors. Indeed, the hotel has had problems with overproduction as well as overheating; the water temperature in the storage tanks reached 98°C in august [24]. Selling the excess heat to the local district heating company, Statkraft Varme, was considered, however the company was not willing to receive the heat. This is because the district heating system has overcapacity in the summertime as well – municipal waste needs to be burned anyway; hence taking in the heat brings no advantage for the district heating system [26]. Selling heat for Rosenborg stadium, which has a large gym, has been considered as another alternative. This solution is under discussion with the relevant parties.

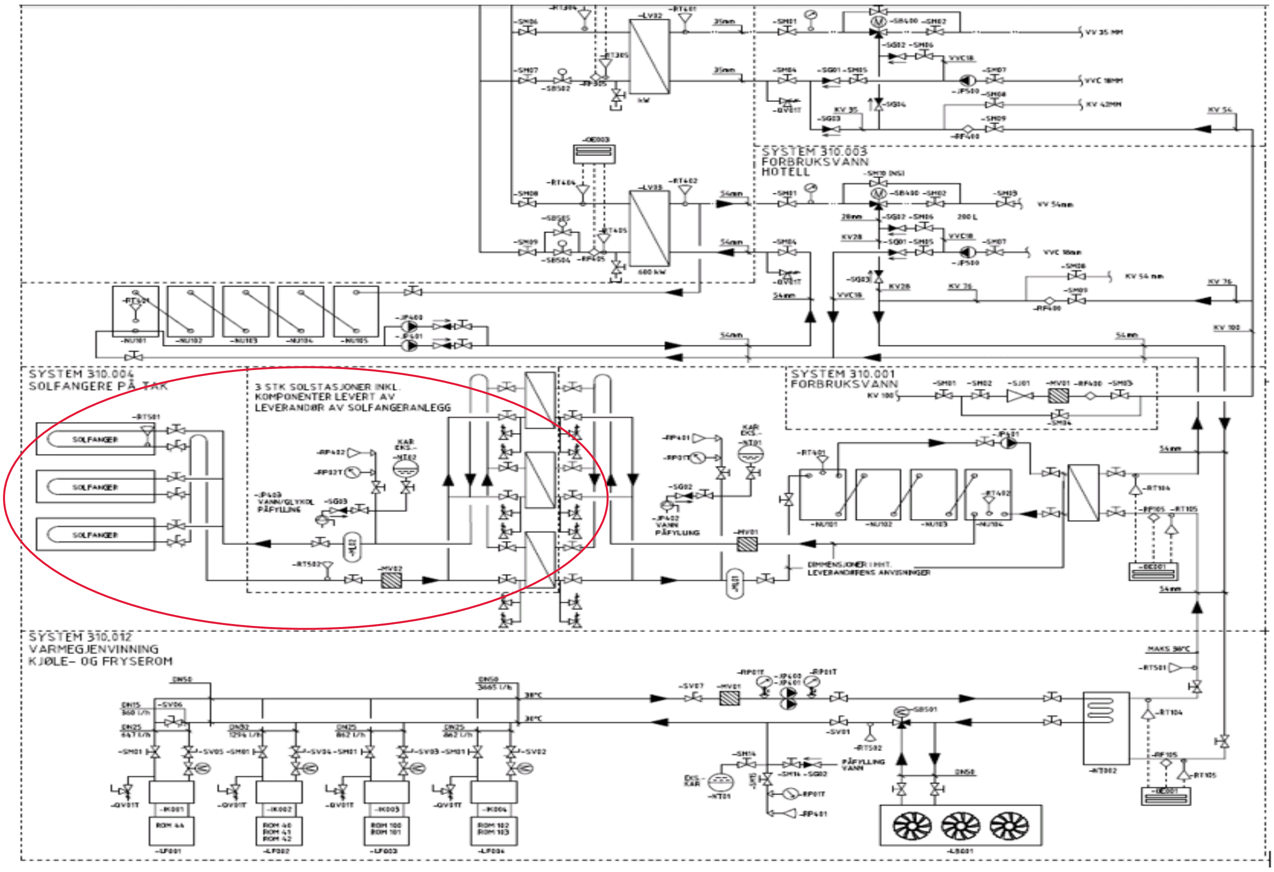


Figure 15 Schematic diagram for the heat supply system at Scandic Hotel Lerkendal. The solar collector circuit is encircled with red. The circuit for heat recovery from the refrigeration system is in the bottom part of the figure.

In general, the hotel has received a lot of positive attention owing to its green profile. Some customers – including conference arrangers – have chosen the hotel because of its special focus on environmental friendliness [24]. On the other hand, the hotel has received some negative feedback from the visitors due to certain energy saving measures, namely the lacking floor heating in the bathrooms. Whether the natural cooling system with night flushing will be able to keep the indoor temperature sufficiently low in the summertime is also a question.

3.3 Bergen University College

The new building for Bergen University College was opened in August 2014, with a total area of 50 983 m² (including a parking garage of 3 650 m²). The building has an annual heating demand of 2 600 MWh and a cooling demand of 1 060 MWh [27]. The installed heating capacity is 2 830 kW, and cooling capacity 3 000 kW. The cooling capacity is relatively high, owing to the high amount excess heat in the summertime from the sun, as well as a high amount of internal loads, such as PCs and IT rooms.

The main principle in designing the energy system for the university college has been to not to dispose any heat, but to store it. For thermal storage, energy wells (81 x 220 m) functioning as a seasonal storage, as well as FlatICE^{TM} cold storage tanks (4 x 60 m^3, biggest in Europe), are employed [27]. The cold storage tanks function as a peak cooling load; if energy wells alone had been used, 180 wells would have been needed to cover the cooling demand. The energy wells together with three liquid chillers are designed to cover 50% of the maximum cooling load [28]. The chillers have a total cooling capacity of 1400 kW and a compressor power of 300 kW, and employ natural refrigerant R717 (ammonium). Without the cold storage, chillers with a cooling capacity of 3000 kW and a compressor power of 700 kW would have been needed – that is, the cooling capacity is reduced by 53% by using thermal storage.

The cold storage tanks are filled with phase change material (PCM) solution (salt hydrate, freezing point at 10°C) encapsulated in sealed elements and stacked on top of each other (see Figure 16) [29]. Water flows in from one end and out from the other end of the tank, and the gap between the elements provides an ideal flow passage for water with a large heat exchange surface. The storage tanks contain in total 47 000 PCM elements, with a cooling capacity of 11 200 kWh (7 hours at 1600 kW).

Figure 16 PCM elements inside the cold storage tanks (left) and cold storage tanks being placed underground at the Bergen University College (right) [27].

To further reduce the cooling power demand, adiabatic cooling is included in 4 cooling aggregates [27]. This means that the temperature of exhaust air is reduced by humidification, which causes the exhaust air to become cooler than the supply air. The supply air can then be cooled down using the same heat exchangers that are in the heating period applied to transfer heat from the exhaust air to supply air. Using adiabatic cooling reduces the cooling power demand by approximately 40%.

The heating demand is covered by the three heat pumps (functioning as chillers in the summer), retrieving heat from the energy wells. For peak heating load, district heating is employed.

A simplified schematic diagram of the heating/cooling system is presented in Figure 17. The system has four operation modes [28]:

A. Low cooling demand: heat pump operation. Heat extraction from the boreholes (bedrock) and some from the cooling system.
B. Moderate cooling demand: chiller operation sufficient. Heat rejection (condenser heat) to the borehole system
C. High cooling demand: chiller operation + melting and PCM. Condenser heat from the liquid chillers to the borehole system.
D. Night operation: charging (freezing, i.e. heat extraction) of PCM storage with the liquid chillers. Condenser heat from the chillers to the borehole system.

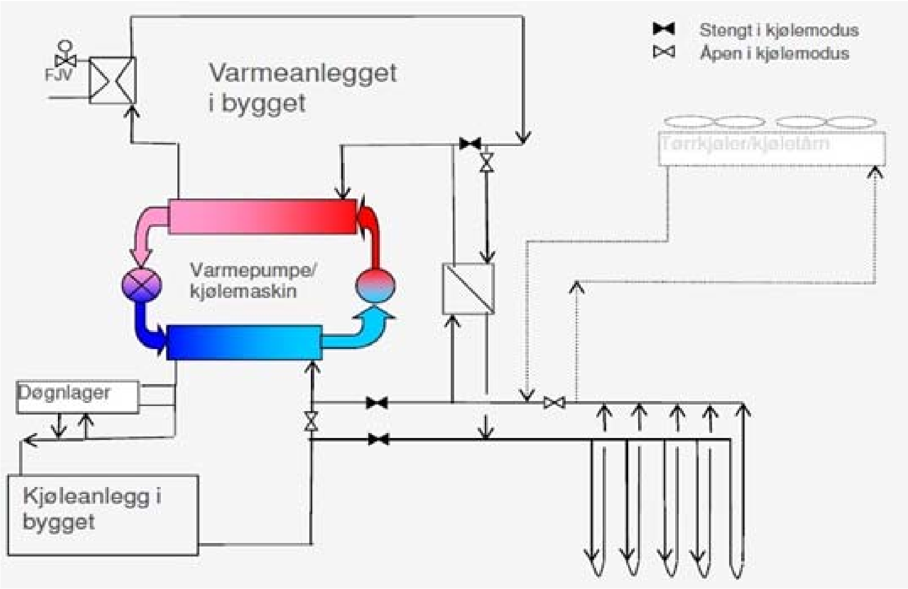


Figure 17 Simplified schematic diagram for the cooling and heating system at Bergen University College [27].

3.4 REMA 1000 Kroppanmarka

REMA 1000 Kroppanmarka, opened in August 2013, is one of the most efficient grocery stores in Northern Europe with approximately 30% lower energy use compared with a similar store with conventional installations [30]. The low energy use was achieved by the following measures, described in more detail below [31]:

- reducing the demand of artificial light by active use of daylight;
- using novel technologies in the ventilation system, adapted for the use in supermarkets;
- utilization of a new generation of R744 booster refrigerant unit;
- storing heat in multi temperature level energy storage;
- smart operation of the heat exchange between these systems;
- tuning of the overall control strategy.

3.4.1 Description of the energy system

Figure 18 is showing a sketch of the integrated energy supply system at Kroppanmarka supermarket. The system consists of mainly five parts. The green lines represent the R744 refrigeration plant (REF), which is the heart of the system. The red lines represent the heat storage (HS) loop. The blue lines present the floor heating (FH) loop, and the black lines show the energy well (EW) loop. The last part is the air handling unit (AHU), which is shown in the upper right corner.

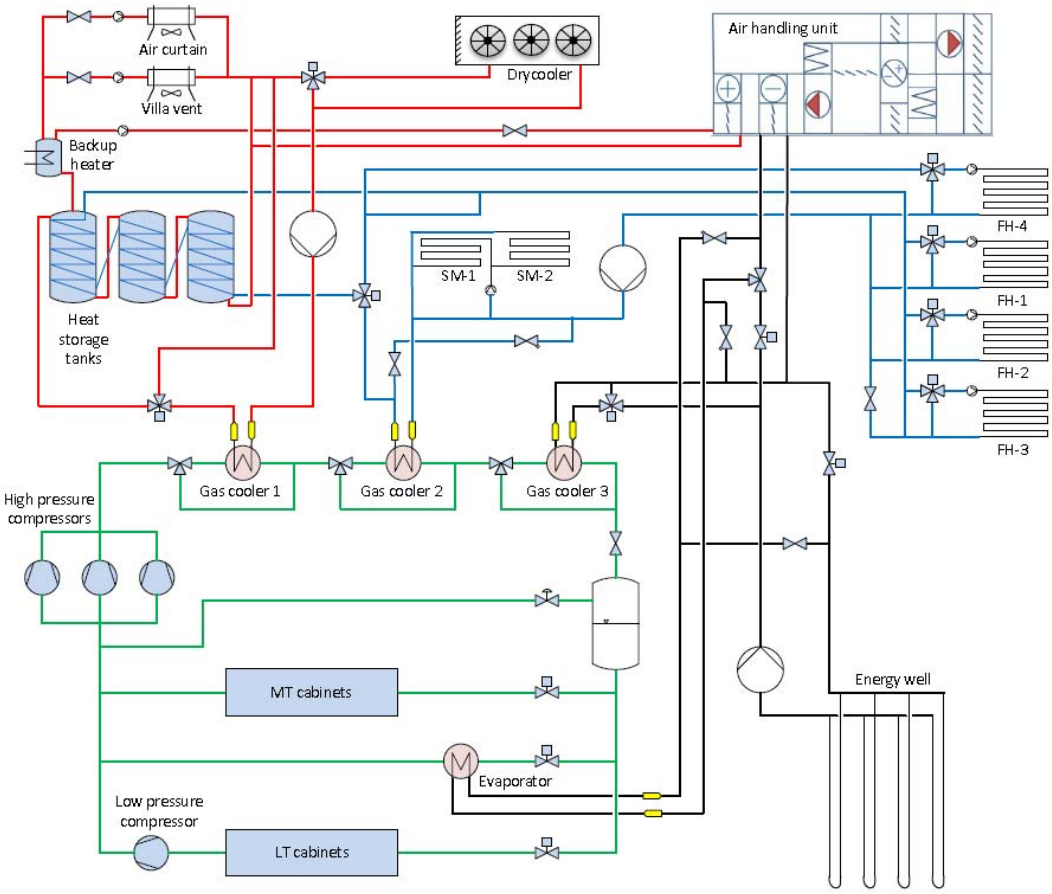


Figure 18 Diagram of the integrated energy system at Kroppanmarka (Jorschick 2014).

Two stage compression and expansion in the R744 cycle assures evaporation at two temperature levels. The evaporation temperature is -35°C in the low-temperature (LT) cabinets (cold rooms and freezers), and -8°C in the medium-temperature (MT) cabinets. There are three compressors with an accumulated compressor power of 73kW at the MT level, and one compressor of 7kW at the LT level [31].

The heat from the REF is delivered to three gas coolers (plate heat exchangers (PHE)) at different temperatures. Gas cooler 1 rejects heat to the HS cycle which is a high-temperature loop. The heat is used primarily to heat ventilation air in the AHU, but could also be used to supply heat to an air curtain at the entrance or the villa vent unit, which supplies heat to the social rooms in the shop. Three hot storage tanks (HST) are also included in the HS loop, and heat can be stored in the tanks in times of low heat demand to be used when the heat demand increases. The total capacity of the storage tanks is 2 700 litres. This is allowing a more steady operation of the compressors, reducing the load peaks and improving the overall efficiency of the system. The HSTs also include spiral heat exchangers connected to the FH cycle, and heat can be transferred from the HSTs to the FH loop. If the HSTs are fully charged, and the heat demand in the building is minimal, the heat can be discharged through a dry cooler to the environment. There is also an electric backup heater included in the system, in case of a major failure in the REF [31].

The inlet temperature of the refrigerant in gas cooler 2 is about 30°C, depending on the temperature distribution in the HSTs, and the heat is used to heat the FH cycle. A mixture of water and a propylene glycol-based fluid is used as heat transfer fluid in the FH cycle. The FH system is divided into four different loops, three under the concrete floor in the sales area, and one underneath the cooling chambers to keep the ground frost-free. In addition, two snow melting circuits are connected to the FH system, and they keep the entrance and service ramp free for snow and ice [31].

The third gas cooler is used to heat the fluid in the energy well (EW) loop. The loop consists of four vertical energy wells with a depth of 170 m each, placed with approximately 8 m spacing. A water-alcohol mixture is used as heat carrier fluid. During the summer, when there is a low heat demand in the shop, the EWs provide free cooling and are contributing to reduce the return temperature of the refrigerant, which is improving the COP of the REF. The EW loop is also connected to the AHU and can provide cooling of the ventilation air. During the winter, the EWs can be used as a heat source to cover the extra heat demand. The EW loop is further connected to an evaporator at the MT level of the REF and can be utilized as an additional cooling load in case of low internal cooling loads from the cabinets and high heating demand in the building [31].

A sketch of the AHU is shown in Figure 19. The main goal of the AHU is to provide thermal comfort and an acceptable indoor air quality. There are mainly five parameters which decide the operation mode of the AHU: ambient temperature, shop temperature, CO_2 concentration, relative humidity and heat available in the HST. A CO_2-sensor is connected to the AHU, and is controlling that outdoor air is only supplied if the CO_2 concentration of the exhaust air exceeds a set point value. In this way the amount of outdoor air delivered to the building, and thereby also the heating demand, is reduced. Heat to the heating coil is delivered from the HST. The heat recovery wheel can be used to preheat the outdoor air, but due to relatively high pressure losses in the wheel, the air is only flowing through the heat exchanger when it is necessary. Cooling is provided either by utilizing outdoor air (if $T_{out} < T_{in}$) or by the EW cycle. The EW cycle can provide either free cooling or active cooling by utilizing the additional evaporator in the REF. The energy use of the AHU is kept low by reducing the internal pressure losses and rotational speed of the fans [31].

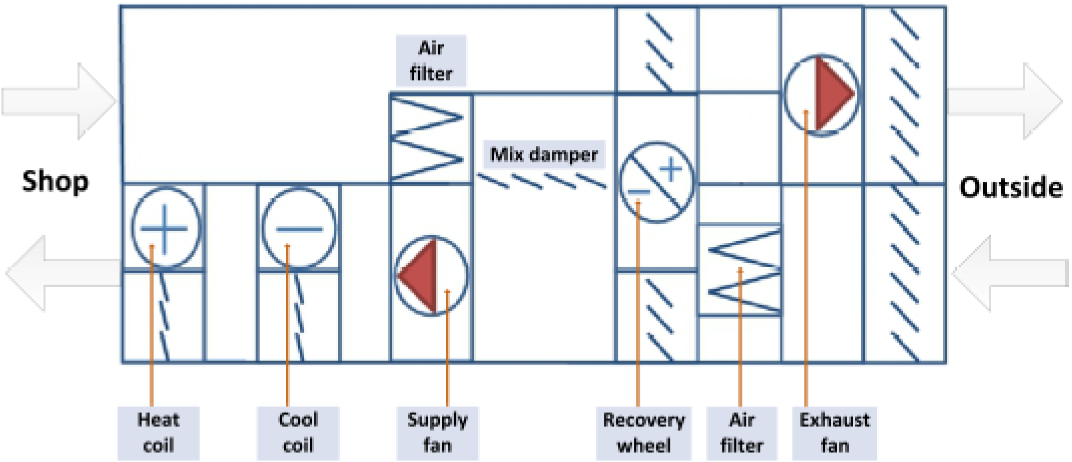


Figure 19 Schematic sketch of the AHU with designation of its main components (Jorschick 2014).

The building in itself is also constructed in an energy efficient way. The walls towards west, north and east are translucent, enabling the utilization of natural light and minimizing the demand for electrical lighting. The material used in the walls, aerogel, is a highly porous material with low thermal conductivity and good transmission characteristics. Solar energy through the walls provides heating as well, however, during the summer, the additional heat has to be removed. The sales floor in the shop is divided into five different zones, and by measuring the background light in each zone, electric lightning is only used when it is needed [31].

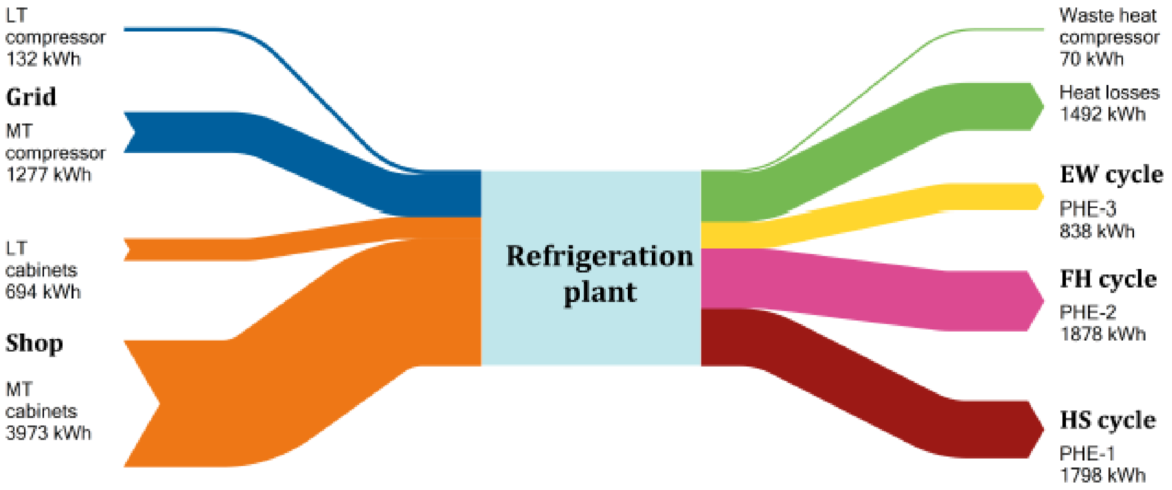
3.4.2 Measurements and experiences

Refrigeration plant

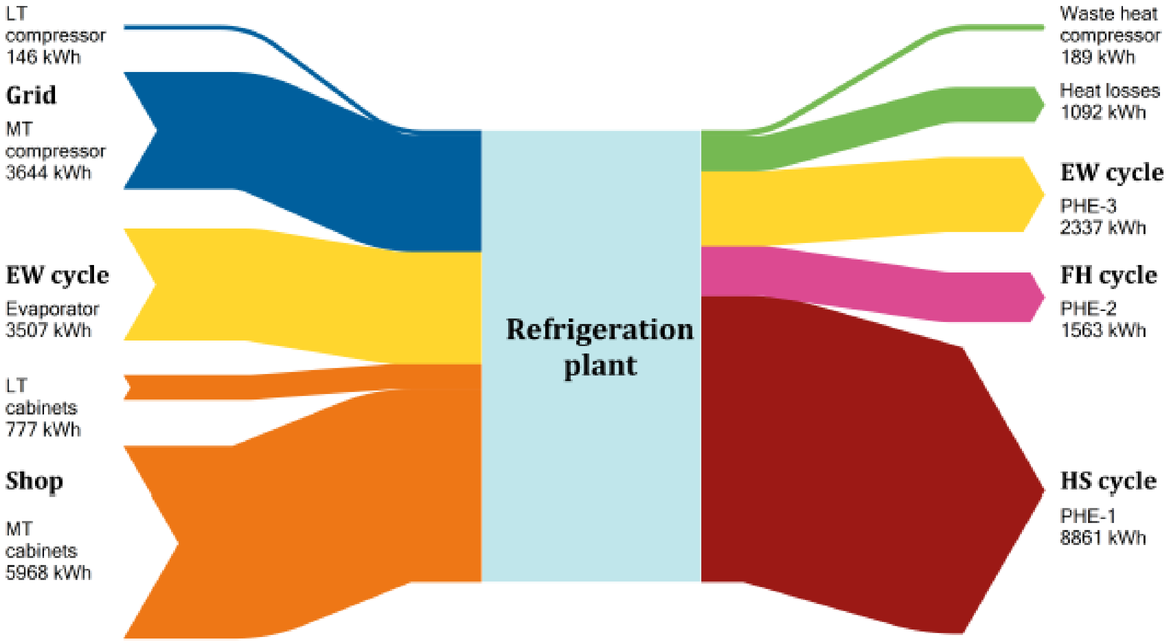
The entire building and the energy system is equipped with a variety of sensors and measuring instruments for process monitoring and control, and to provide data for scientific analysis and evaluation of the system. Jorschick [31] has collected and analyzed data from three different periods during 2014. To analyze the operation mode for the spring and the summer, the periods from 9th to 15th of April and 9th to 15th of July were selected. Due to some missing values, the winter period could not be fully analyzed for the REF. The energy flows for the spring and summer period is shown in Figure 20.

During the spring period, the average compressor power consumption was 8.4 kW and the average supplied cooling capacity was 27.8 kW, resulting in an average COP of 3.3. 31% of the recovered heat was transmitted to the FH cycle, 29% to the HS cycle and 14% to the EW cycle. The rest of the heat (26%) leaved the system as waste heat [31].

The analyzed summer period was the warmest period of the year with an average temperature 8 K higher than the long-term average for July. The period is hence not representative for a usual summer, but can be used for evaluation of the energy system on hot days. Due to the high temperature, the compressors used much more energy than during the spring period, and subcooling of the glycol in the EW loop was used to air cooling. The average cooling capacity, including subcooling of the glycol, was 61 kW and the average compressor power was 22.6 kW, resulting in a COP of 2.7. Most of the heat from the gas cooler (63%) was transmitted to the HS loop, 11% to the FH loops, and 17% to the EW loop. 9 % of the heat leaved the system as waste heat. Almost 90 % of the heat transmitted to the HS loop was delivered to the environment via the dry cooler [31].



(a) Spring



(b) Summer

Figure 20 Sankey diagram of the energy flows of the refrigeration plant for the spring and summer periods (Jorschick 2014).

Air handling unit

The heat flows in the AHU were also analyzed, and in this case good data was available for all the three periods. During the winter period, air is mostly recirculated due to the high heat requirement for heating the cold outdoor air: the ratio between recirculated and outdoor air was on average 7.6. The supply air temperature varied between 17 and 21°C. If the temperature drops below 17°C, the air is heated by the heating coil. During the spring period, the AHU was off during the night and operated similarly to the winter operating mode during the day, but the ratio between recirculated and outdoor air was on average 3.3. During this period the heating coil was rarely used, and never reached full capacity. In both these periods the AHU was able to maintain the shop temperature at a constant level of (20±1) °C [31].

During the summer period, the AHU is operating in two different modes. If the outdoor temperature is higher than the indoor temperature, the air is recirculated in the AHU and cooled by the cooling coil. The maximum cooling power in this mode is 27.5 kW. If the outdoor temperature is lower than the indoor temperature, the outdoor air is used for cooling and further cooled by the cooling coil. In this mode the maximum cooling power is 38.5kW. The average air temperature from the shop was 24.5°C in this period, and the maximum temperature was 28°C.

The experiences so far have hence showed that the AHU operated satisfactory during the winter and spring, but the high indoor temperature during the summer is not acceptable. Such high indoor temperature leads to spoiled food and reduced comfort, and increases the energy use of the refrigeration plant and plug-in devices. Active shading could be used to reduce the heat gains through the windows and the aerogel surfaces in the summertime [31].

Energy use

The energy use at Kroppanmarka supermarket was compared with conventional supermarkets with similar size in the same area, and the comparison is shown in Figure 21. During the winter and the spring, the energy use was more than 30 % lower, but during the summer, the energy use was almost similar with the other supermarkets. The challenges during the summer operation could however be solved by installing shading, as mentioned above. The annual specific energy use of Kroppanmarka supermarket is approximately 330 kWh/m², which is 45% less than the specific energy use of the supermarkets presented in section 2.2.

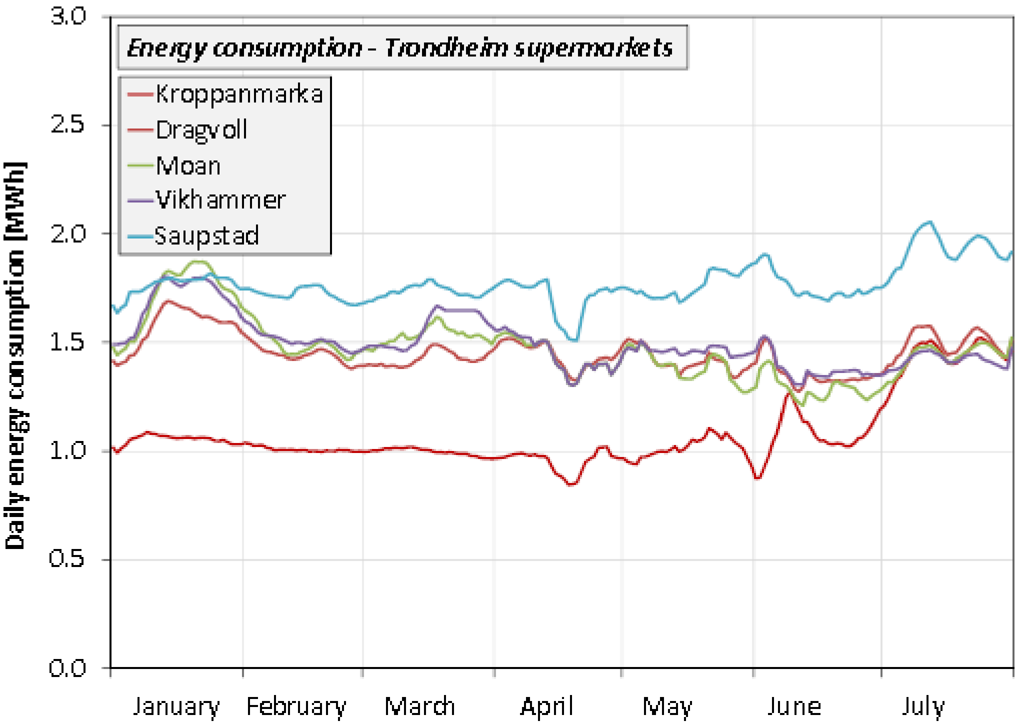


Figure 21 Energy consumption at Kroppanmarka compared with conventional supermarkets of similar size, from January to July 2014 [31].

3.5 Vulkan energy plant

The energy plant at Vulkan is a complex energy plant located in Oslo. The plant provides heating and cooling to seven buildings: Bellona, Fabrikken, PS Hotell, Scandic, Mathallen, Søndre Kvartal and Nordre Kvartal. Out of these, Bellona and Fabrikken are office buildings; PS Hotell and Scandic are hotels; Mathallen consists of small food stores, cafes and restaurants; and Nordre and Søndre Kvartal contain shops, a grocery store and cafes. All the buildings are built according to high energy standards, either in energy class A (passive house according to NS3701:2012) or B (low energy building according to NS3701). Bellona (heated areal 3 120 m²) is one of the buildings fulfilling the requirements for energy class A, and has a calculated specific energy demand of 96 kWh/m² year, out of which 76 kWh/m² is delivered energy [32].

To supply the heating and cooling demand, the energy plant utilizes geothermal heat from in total 64 energy wells, each 300 m deep. Additionally, waste heat from the refrigeration system at Mathallen is utilized, and Bellona has solar thermal collectors installed on its facade. The plant has a heating capacity of 3 375 kW and a cooling capacity of 1 848 kW, and a total annual energy delivery of 4.5 GWh (including heating and cooling). For short-term energy storage, the plant has hot water storage of in total 10 000 l at ca 50°C, and a cold storage of 2 000 l at ca 4°C [33].

3.5.1 Operating modes

The energy plant has mainly three different operating modes; heating, free cooling and active cooling, described in more detail below. In addition there is a mode called solar collector mode that can be combined with all the other modes. It is also possible to combine the different modes to optimize the operation. This could be done in periods with big temperature differences during a day, for example during the spring or fall.

3.5.1.1 Heating mode

Figure 22 shows a simplified plant sketch with the heat flows when the plant is operating in the heating mode. The heat pumps utilize heat from the energy wells and from the cooling circuit in Mathallen. If there are cooling demands in other parts of the system, this can also be used as a heat source for the heat pump as is shown in Figure 22. Condenser heat is accumulated in the storage tanks and is further used to provide heating to the buildings. Solar thermal heat is also stored in the hot storage tanks. Due to temperature limitations of the heat pumps, district heating is needed to provide heating of DHW. District heating can also be used as a backup if the energy plant does not provide enough heat by itself.

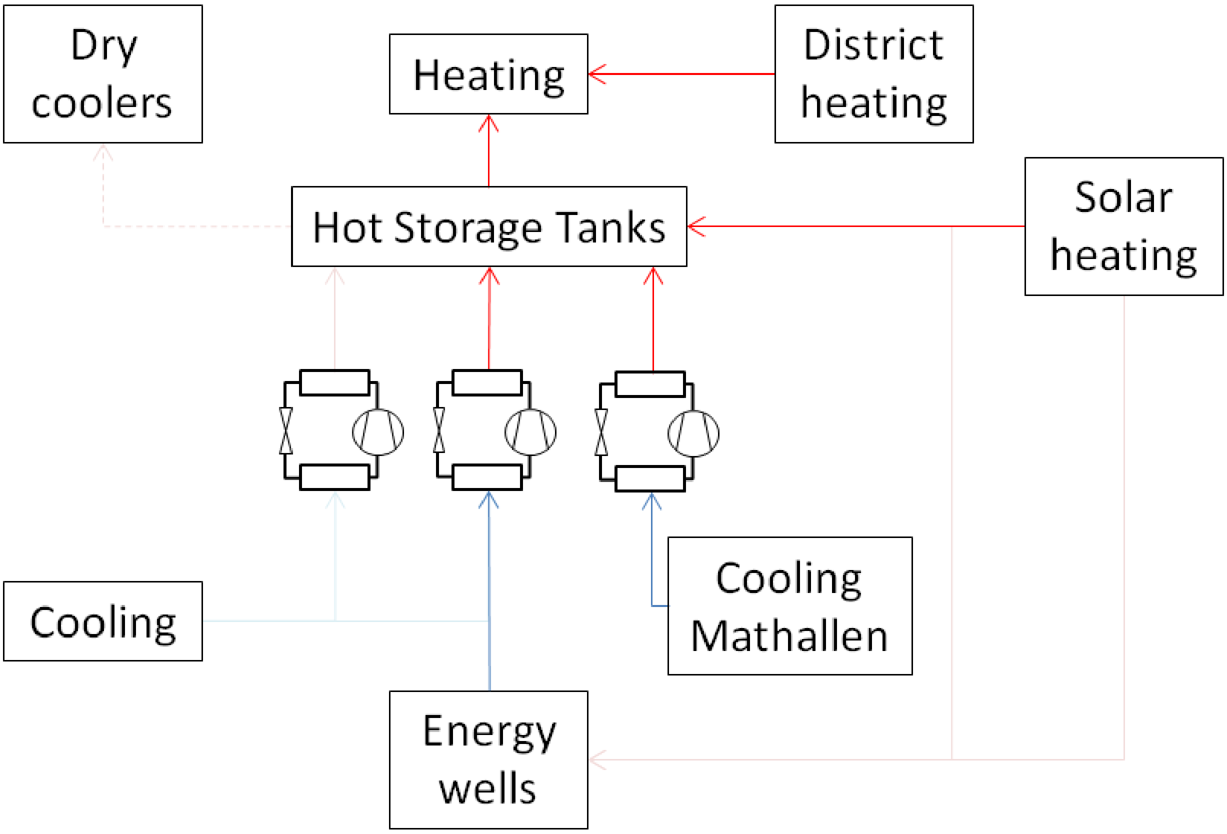


Figure 22 Schematic diagram of the heat flows at the energy plant at Vulkan when operating in heating mode.

3.5.1.2 Free cooling mode

In periods with a relatively low cooling and heating demand and when the energy wells are cold, the plant operates in the free cooling mode, see Figure 23. This could typically occur in the spring, when the wells are cooled down after delivering heat during the winter. In this operating mode, the anti-freezing solution flows directly between the cooling heat exchanger and the energy wells, and the only operating heat pump is the one that provides cooling in Mathallen, where lower temperatures are needed for food storage. The required heating is provided by the heat from the operating heat pump and district heating, in combination with solar heating when available. It is always necessary to consider whether it is favorable to operate the plant in this mode and buy district heat to provide the DHW and room heating demands, or operate in the active cooling mode where surplus heat can be used to preheat DHW and to heat the buildings.

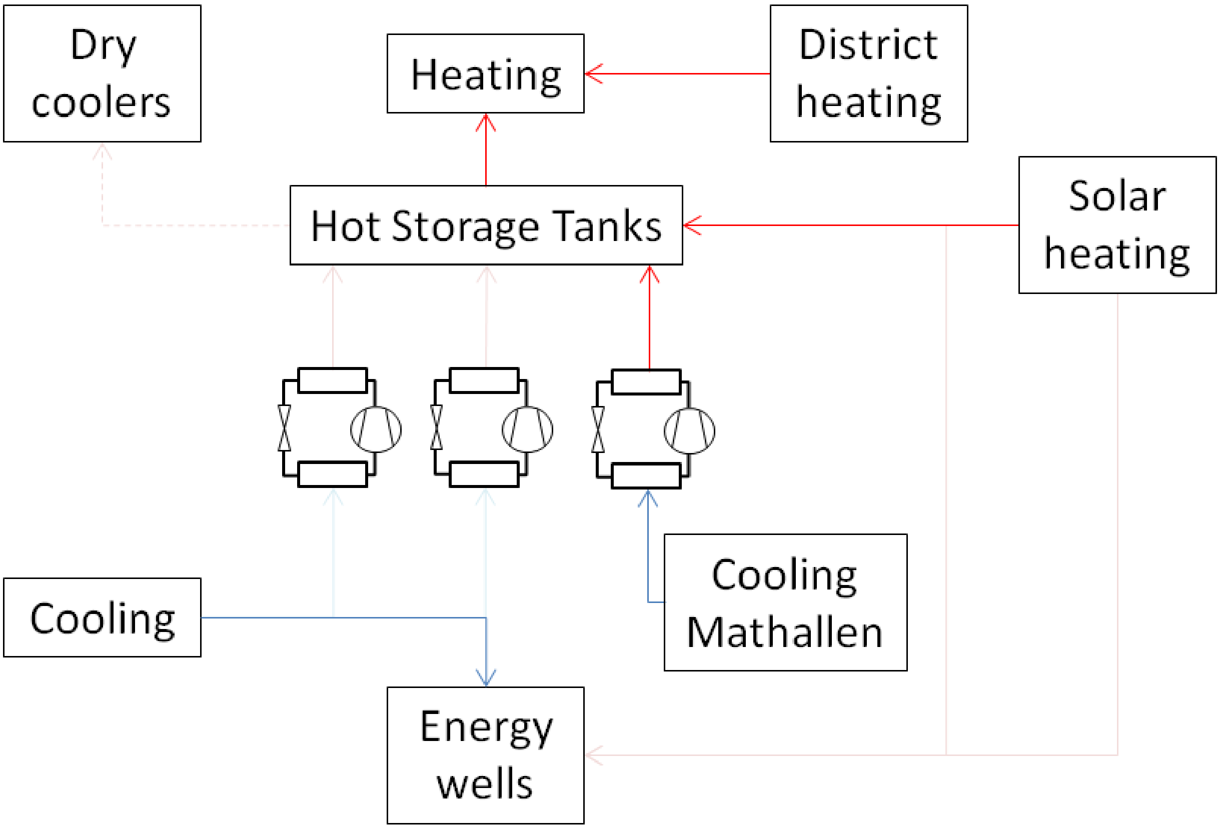


Figure 23 Schematic diagram of the heat flows at the energy plant when operating in free cooling mode.

3.5.1.3 Active cooling mode

The diagram in Figure 24 shows the heat flows when the plant is operating in the active cooling mode, where the heat pumps are providing cooling to the buildings and to Mathallen. The heat is used to heat the hot storage tanks and provide heating to the buildings. In the case there is more heat available than what is needed for the buildings, the heat can be stored in the energy wells. District heating is used to provide DHW because it requires higher temperature than the heat pumps can provide. Solar collectors can either deliver heat to the hot storage tanks or to the energy wells.

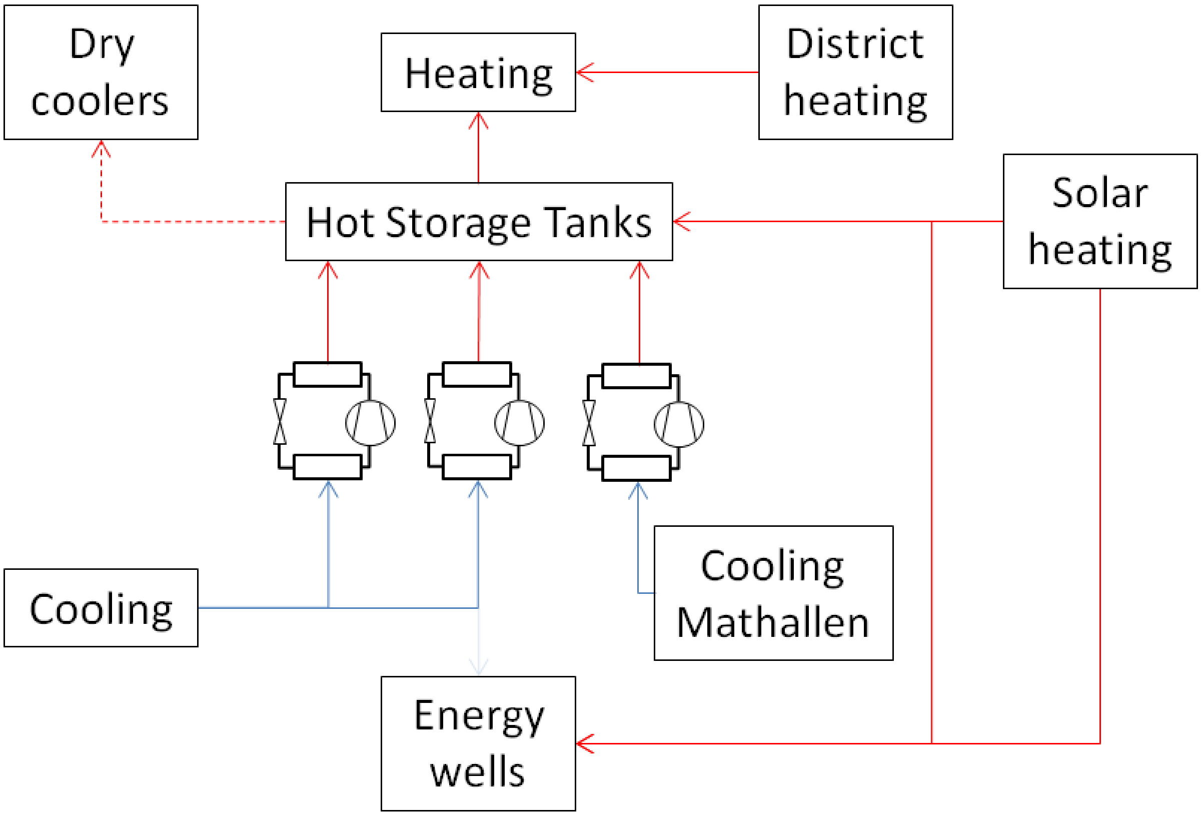


Figure 24 Schematic diagram of the heat flows at the energy plant when operating in active cooling mode.

3.5.2 Measurements and experiences

Figure 25 presents the monthly heating and cooling load delivered to the individual buildings at Vulkan by the energy plant for the first half of 2014. As expected, the heating demand decreases and cooling demand increases towards the summer, apart from the refrigeration system at Mathallen, which has a relatively even, high cooling demand. Figure 26 presents additionally the total hourly heating and cooling demand. From this figure it is evident that the heating demand is significantly higher than the cooling demand.

The hourly values for the COP of the plant are presented in Figure 27. The COP was approximately 3 for the winter season, but drops to approximately 1.5 in the summer. The average COP for the period was 0.5 for cooling, 2.04 for heating and 2.55 in total.

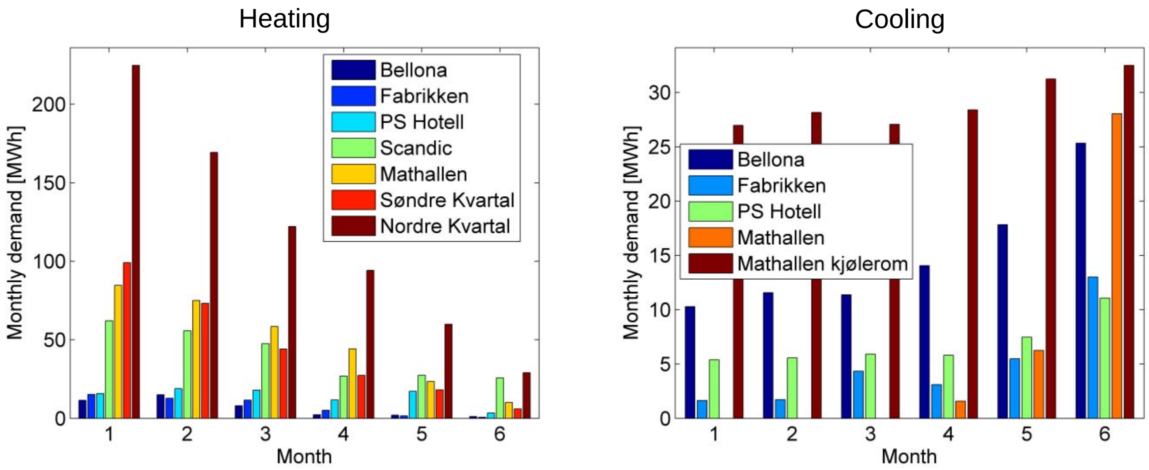


Figure 25 Monthly heating (left) and cooling (right) demand delivered to the individual buildings at Vulkan by the energy plant for the first half of 2014.

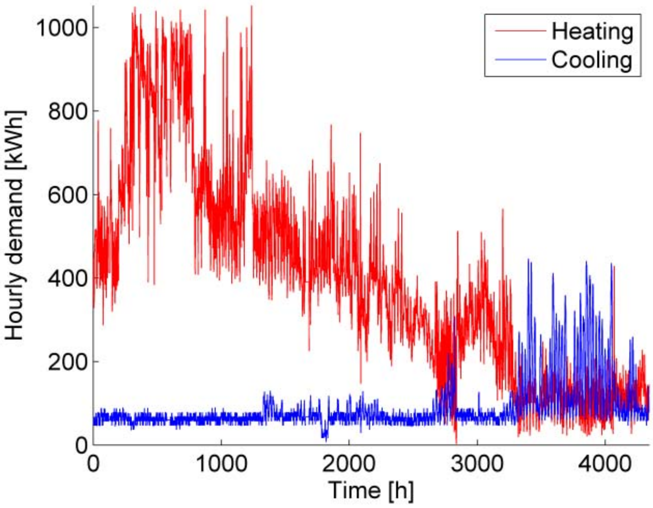


Figure 26 Hourly total heating and cooling demand of the energy plant for the first half of 2014.

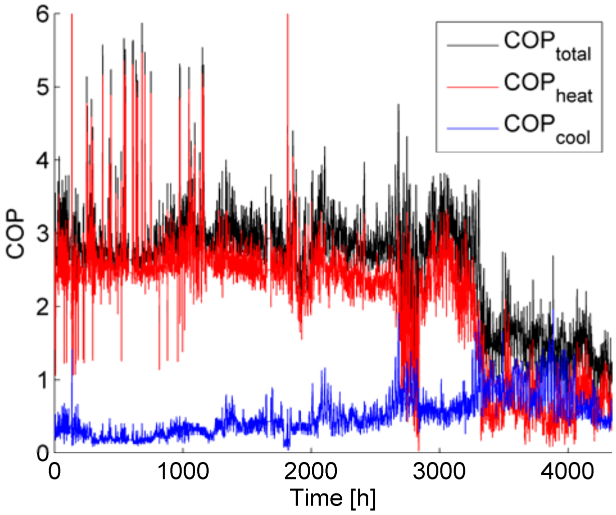


Figure 27 The hourly heating, cooling and total COP of the energy plant for the first half of 2014.

The total heating, cooling, electricity and district heating demand, as well as the heat delivered to the energy wells and collected solar heat for the first half of 2014, are summarized in Table 1. The district heating demand is relatively high – approximately 25% of the total heating demand. If the existing system could cover all the heating demand by the heat pump system, the amount of energy sold from the energy plant would increase and decrease the amount of purchased heat energy from the district heat system. Consequently the COP would be increased as well.

Table 1 Total heating, cooling, electricity and district heating demand, as well as the heat delivered to the energy wells and collected solar heat.

	Total demand (MWh)
Heating	1695
Cooling	378
Electricity	817
District heating	423
Heat to energy wells	45
Solar heat	12

3.6 Gardermoen energy plant

The thermal energy plant at Gardermoen Airport was built in two steps. The first part was built in 1998 to cover heating and cooling demand for a total area of 144 000 m^2. The cooling demand was calculated to 9 MW and the heating demand to 20 MW, partly provided by ammonia heat pumps utilizing the ground water as a heat source and sink. The heat pumps had a heating capacity of 8 MW, and a cooling capacity of 6 MW. The ground water provides free cooling with a capacity of 3 MW, and the remaining cooling demand was provided by the heat pumps in cooling mode. The base heating demand is provided by the heat pumps, and district heating is used to cover the peak load.

Due to extension of the airport, the heating and cooling demands have increased. The new cooling and heating demands are calculated to 20 MW and 35 MW, respectively. A new heat pump was installed to the energy plant in 2013 to cover the increased demand, and instead of increasing the number of ground water wells, treated wastewater is used as heat source and sink. The new heat pump has a heating capacity of 5 MW, and a cooling capacity of 4 MW. A sketch of the plant is shown in Figure 28.

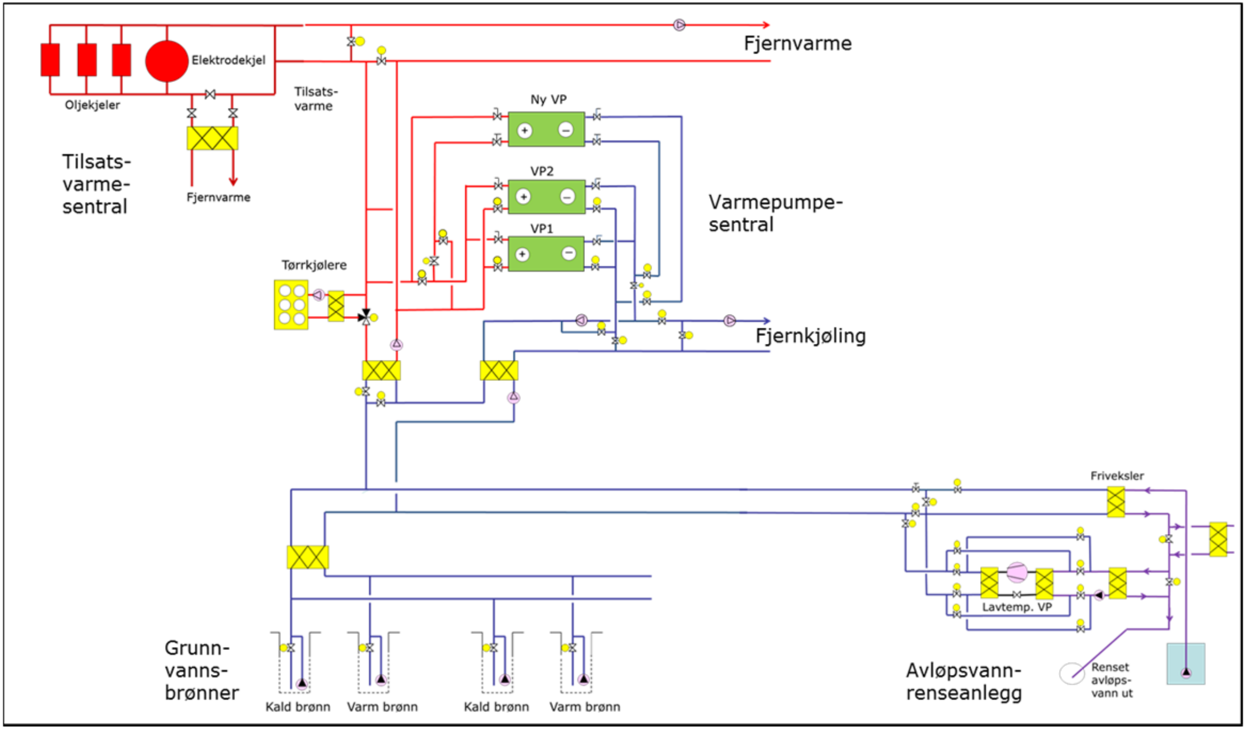


Figure 28 Schematic diagram of the thermal energy plant at Gardermoen (G. Eggen, COWI AS).

When operating in cooling mode, the cooling water is first cooled with free cooling from the ground water or wastewater and then further cooled by the evaporator of the heat pumps if necessary. The evaporator of the new heat pump is normally connected in series with the other heat pumps when operating in this mode, but it could also be connected in parallel. The condenser is connected in parallel.

Free cooling and cooling by the heat pumps gives a total cooling capacity of 15 MW, but the total cooling demand is calculated to 20 MW. A snow storage system, illustrated in Figure 29, has been planned to provide the remaining cooling demand of 5 MW. The meltwater from the snow storage will cool the cooling water, and the heated melt water will flow back to the snow storage, melting more snow. This is a more or less self-regulating system as when the cooling demand is increased, more heat is released to the snow storage, and more meltwater is produced. When the amount of snow is reduced, some of the water is drained out of the system.

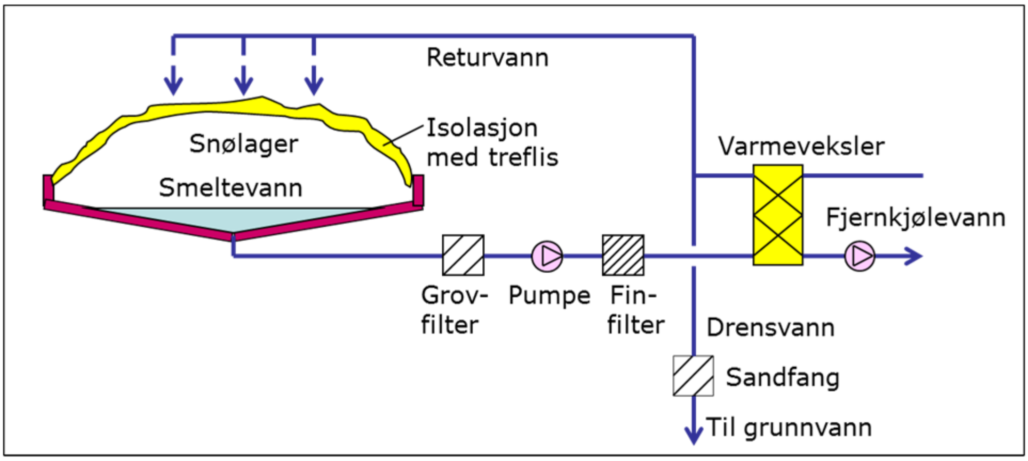


Figure 29 Sketch of the snow storage system for peak cooling (G. Eggen, COWI AS).

The energy plant consists of three ammonia heat pumps, out of which two are equipped with piston compressors and one with a screw compressor. The heat pumps with piston compressors can produce water at a temperature of 45°C, and the heat pump with a screw compressor can provide water at 55°C, and the condenser of this heat pump is normally connected in series with the other condensers. In the heating mode, the ground water wells are primary used as heat source. There are nine warm and nine cold wells, and when operating in heating mode, the water from the warm wells is used as a heat source for the heat pumps. During summer, the water flow is reversed and water from the cold wells is used as a heat sink. It is important to cool the water during the winter so that cold water is available for cooling during the summer. If the heat from the ground water wells is not enough, heat from the waste water is used as a heat source. A low-temperature heat pump has been installed in the wastewater system to provide higher temperature to the main heat pumps in the energy plant to increase their capacity.

The duration curves for heating and cooling are shown in Figure 30. The base load for heating is covered by the heat pumps (11 MW), and the peak load is primary covered by district heating based on bioenergy (7.5MW). When these two renewable energy sources are insufficient, an electric boiler of 10 MW and three oil burners of 8.5 MW are used. The base load for cooling is provided by free cooling, and the heat pumps in cooling mode provide an additional 10 MW. The remaining 5 MW is covered by the snow storage system.

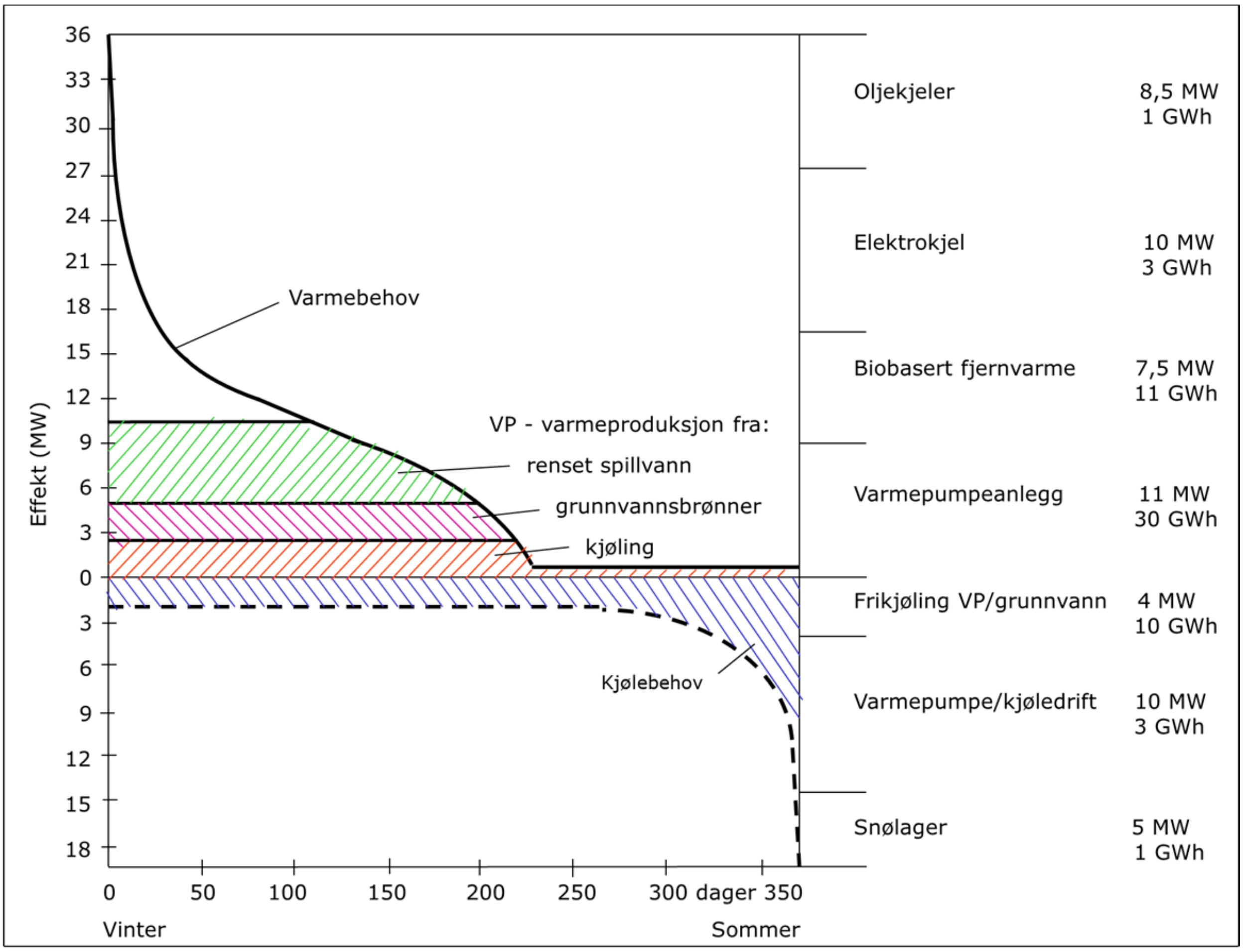


Figure 30 Power duration curve for Gardermoen (G. Eggen, COWI AS).

4 Conclusions

In this report, an overview of the energy use in different non-residential buildings has been given, together with case studies of individual buildings or building complexes with integrated energy solutions and systems for utilization of surplus heat.

The biggest learning outcomes regarding the energy use in different building categories have been, firstly, that the energy use according to the purpose varies a lot for the different building types; hospitals being characterised by high demand for heating through ventilation, offices and universities by high energy use for technical equipment, shopping centres with high amount of energy required for lighting, hotels by high DHW demand, and so forth. This is important to take into account when planning energy supply systems and energy efficiency measures for different buildings. Secondly, the calculated and measured energy uses deviate from each other such that the actual energy use is generally higher than the calculated use for new buildings, and vice versa for old buildings. Furthermore, for most building categories, the measured specific energy use is hardly lower for newer than for older buildings, despite the tightening building regulations. This is related to for instance lengthened operation times, increased amount of technical equipment, higher requirements for indoor air quality, and non-optimal operation and use of the building. To actually reduce the energy use in buildings, the energy efficiency of technical equipment has to be increased, and the users and operators of the building have to be engaged in reducing the energy use, to mention but few.

Regarding the case studies of individual buildings and building complexes, it has been noted that in many cases thermal energy storage plays a central role in utilizing excess heat. Energy wells are becoming a common choice for seasonal thermal storage. A closed system is employed at for instance at Rema 1000 Kroppanmarka, Bergen University College and Vulkan Energy Plant, and an open system is used at Gardermoen Airport. Another way of storing thermal energy from one season to another is snow storage, which is being planned for Gardermoen. For short-term thermal storage, a less traditional solution, namely PCM cold storage tanks, was introduced at the Bergen University College. At Scandic Hotel Lerkendal, where solar collectors are utilized for heat production and the heating demand is dominated by DHW, large hot water storage tanks are employed. Energy wells could have been a possible solution for storing the excess heat produced in the summertime; however this problem will in the future perhaps be solved by supplying the heat to a nearby gym. At the AHL-centre at St Olav's hospital, no thermal energy storage is utilized – but this was also identified as one of the barriers for better utilization of waste heat from the refrigeration system. Finally, it can be concluded that the integrated energy systems for waste heat utilization include energy storage, heat pumps, and a connection to the district heating system to cover the peak load.

From the case studies it can further be concluded that utilization of waste heat is a good energy efficiency measure. In the case of the Kroppanmarka supermarket, for instance, a great deal of the heating demand is covered by the waste heat from the refrigeration system. At the AHL-centre at St Olav's hospital, the heat recovered from the refrigeration system corresponded to only 4% of the district heating demand; however discarding this heat would result in a significant (26%) increase in the cooling demand.

Interaction of the energy supply of different buildings for better utilization of waste heat is however so far little practiced – the energy plant at Vulkan is the only example presented here, and one of a kind in Norway. A route for increased building interaction is the possibility for third-party access to district heating networks, discussed further in the report "Policy and regulatory framework for energy efficiency in Norway" in WP4 of the INTERACT project. Another solution is the further development of local smart thermal grids; this possibility will be investigated in the future project RISVOLLAN[3].

---

[3] The innovation project for the industrial sector 'Utilization of local surplus heat and renewable heat sources in Risvollan smart thermal grid – RISVOLLAN' is a 3-year project (2015-17) with main funding from industrial partners and the Research Council of Norway, and coordinated by SINTEF Energy Research.

5 References

1. UNEP SBCI *Buildings and Climate Change: Summary for Decision Makers*. 2009.
2. Abrahamsen, A.S., M. Bergh, and N. Fedoryshyn, *Energibruk i bygninger for tjenesteytende virksomhet, 2011*. 2013, Statistisk sentralbyrå.
3. International Energy Agency (IEA), *Transition to Sustainable Buildings: Strategies and Opportunities to 2050*. 2013.
4. Lawrence Berkeley National Laboratory. *What is energy efficiency?* 2014 17.12.2014]; Available from: http://eetd.lbl.gov/ee/ee-1.html.
5. Kampel, W., B. Aas, and A. Bruland, *Energy-use in Norwegian swimming halls*. Energy and Buildings, 2013. **59**: p. 181–186.
6. SSB. *Energibruk i husholdningene, 2012*. 2014 14.6.2014 1.12.2014]; Available from: http://www.ssb.no/energi-og-industri/statistikker/husenergi.
7. Abrahamsen, A.S. and M. Bergh, *Energibruk i bygninger for tjenesteytende virksomhet, 2008*. 2011, Statistisk sentralbyrå.
8. SSB. *Bygningsmassen, 1. januar 2014*. 2014 13.11.2014]; Available from: http://www.ssb.no/bygningsmasse.
9. Bøhn, T.I., et al., *Potensial- og barrierestudie: Energieffektivisering i norske yrkesbygg*. 2011, Enova.
10. Fiksen, K., et al., *Energibruk i kontorbygg – trender og drivere*. 2012, THEMA Consulting Group.
11. Multiconsult AS, Analyse & Strategi, and Entro AS, *Analyse av energibruk i forretningsbygg*. 2014, NVE.
12. Energimyndigheten, *Förbättrad energistatistik för lokaler – "Stegvis STIL" Rapport för år 1. Inventeringar av kontor och förvaltningsbyggnader*. 2007.
13. Martinez, R., et al., *Energibruk i sykehus, status over energikrevende funksjonskrav og faktisk forbruk knyttet til bygg og utstyr og muligheter for energieffektivisering*. 2011, Innovasjonsprosjekt Lavenergisykehus
14. Aasen, R.E., *Vurdering og utnyttelse av spillvarme i sykehus generert fra kjølemaskiner.*, in *Institute for energy and process technology*. 2013, Norwegian University of Science and Technology.
15. Rohde, T. and R. Martinez, *Hospital Equipment and Energy Usage*. 2014, Applied research project «Low Energy Hospitals».
16. Multiconsult AS, Analyse & Strategi AS, and Entro AS, *Analyse av energibruk i undervisningsbygg*. 2014, NVE.
17. SSB, *Energibruk i tjenesteytende næringer, 2011, endelige tall*. 2013.
18. Enova, *Enovas Byggstatistikk 2011*. 2011.
19. Helsebygg Midt-Norge. *Nye oppdrag for helsebygg*. 2014 28.11.2014]; Available from: http://www.helsebygg.no/.
20. Helsebygg Midt-Norge. *Bygger ny kjølesentral*. 2004 18.5.2004 28.11.2014]; Available from: http://www.helsebygg.no/nyheter2004/21506/.
21. Helsebygg Midt-Norge. *Kunnskapssenteret*. 2013 10.12.2013 1.12.2014]; Available from: http://www.helsebygg.no/miljosenteret/.
22. Abrahamsen, L., *Prosjektbeskrivelse: Kunnskapssenteret - St. Olavs hospital, Trondheim*. 2010.
23. Emmerhoff, T., *Solfangeranlegg på Lerkendal Hotell*. 2014.
24. Høili, L., *Personal communication about the heat supply system at Scandic Hotel Lerkendal*, H. Kauko, Editor. 2014.
25. ProgramByggerne. *SIMIEN*. 2014 5.12.2014]; Available from: http://www.programbyggerne.no/.
26. Brenne, A., *Taking in excess heat to district heating network in the summertime (personal communication through email)*. H. Kauko, Editor. 2015.
27. Dar, U., *Høgskolen i Bergen Energisentral*. 2014, SWECO.

28. Stene, J., *Heating/Cooling of Academy Buildings. The University of Bergen – New Buildings/Renovation (2014)*. 2014.
29. PCM Products Ltd. *PlusICE Phase Change Materials* 2011 11.12.2014]; Available from: http://www.pcmproducts.net/files/thermal_storage_catalogue.pdf.
30. Tekniske Nyheter (2014) *Energisparepris til Sintef og Rema*.
31. Jorschick, H., *Measurement and Evaluation of Energy Integrated Supermarkets Concept.*, in *Department of Energy and Process Engineering*. 2014, Norwegian University of Science and Technology.
32. FutureBuilt. *Bellonahuset*. 2014 2.12.2014 4.12.2014]; Available from: http://www.futurebuilt.no/prosjektvisning?projectid=205920.
33. Joelson, T. *Vulkan åpner energisentral*. 2010 27.11.2013 4.12.2014]; Available from: http://www.bygg.no/article/66163.

SINTEF

Technology for a better society

www.sintef.no